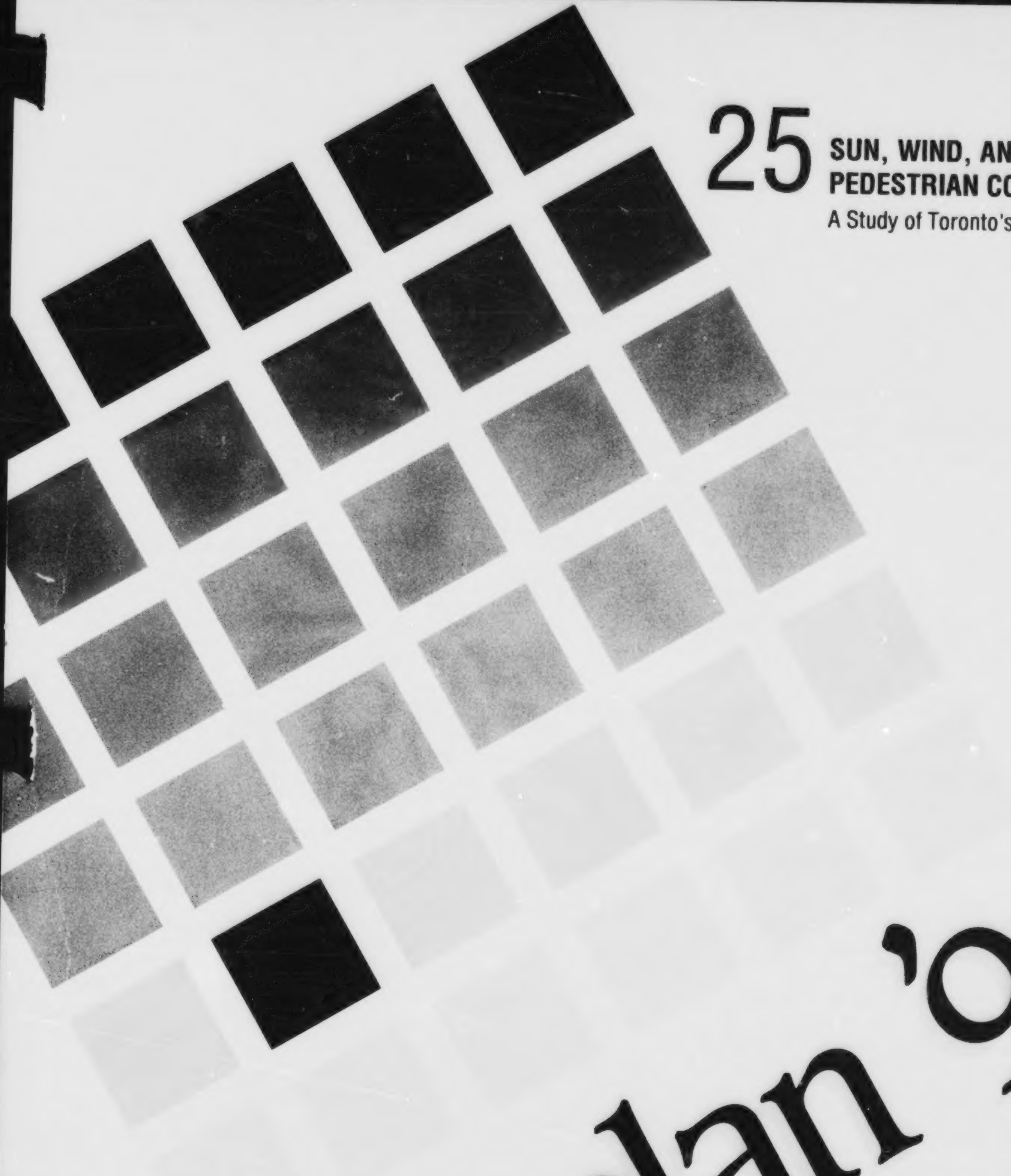

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SUN, WIND, AND PEDESTRIAN COMFORT

A Study of Toronto's Central Area

Cityplan '91

City of Toronto
Planning &
Development
Department

Robert E. Millward
Commissioner

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December 1990

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Prepared for the City of Toronto Planning
and Development Department by:
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City of Toronto
**Planning &
Development**
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The Department of Planning and Development
City of Toronto

April 1991

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Table of Contents

1. Summary 1
- Study Areas and Procedure 1
- Key Findings 2

2. Introduction 5
- Need for this Study 5
- Purpose of this Study 5
- Background for this Study 5
- Sun, Wind, Comfort, and Scale in Urban Design 8
- Climate and Comfort in Toronto 12
- Winds in Toronto 15
- Sunlight on Toronto Streets 19

3. Study Method 25
- 3.1 Field Studies Methodology 27
- 3.2 Laboratory Studies Methodology 30
  - 3.2.1 Modeling of Development Scenarios on Selected Sites 36
  - 3.2.2 Methodology for Sunlight Analysis 41
  - 3.2.3 Wind Tunnel Testing 41
  - 3.2.4 Thermal Comfort Modeling 42

4. Analysis 45
- 4.1 Field Study Analysis 45
  - 4.1.1 Field Studies - Sunlight on Streets 45
  - 4.1.2 Sunlight for Open Spaces 49
- 4.2 Laboratory Analysis 53
  - 4.2.1 North Midtown, Bloor Street Area 56
  - 4.2.2 East Downtown 72
  - 4.2.3 Railway Lands / Lakefront Area 84

5. Findings and Conclusions 95

6. Recommendations 103
  6.1 Sun Access for Streets in the Central Area 103
    6.1.1 Street Classification System 104
    6.1.2 Sun Access Standards for Streets 106
    6.1.3 Implementation of Sun Access Controls for Streets 110
  6.2 Sun Access for Parks and Other Open Spaces in the Central Area 113
    6.2.1 Open Space Classification as a Basis of Sun Access Standards 113
    6.2.2 Standards for Different Types of Open Spaces 114
    6.2.3 Implementation of Sun Access to Open Spaces 122
    6.2.4 The Use of Performance Standards to Implement Sun Access to Open spaces 122
    Solar Fans 123
  6.3 Standards for Protection from Adverse Wind Conditions 138

7. Implementation 141
  Urban Design Studies of Selected City Blocks 141
  Streets For All Seasons 151

Appendix I 157
  1.1 Wind Tunnel Procedure 157
  1.2 Methodology for Wind Tunnel Testing 168
  1.3 Thermal Comfort Modeling 174

Appendix II Review of Sun and Wind Ordinances and Planning Controls in North American Cities 179
  Canadian Cities 180
  United States Cities 182

1. SUMMARY

This report describes a joint urban design study by the Center for Environmental Design Research at the University of California at Berkeley and the Centre for Landscape Research at the University of Toronto. The purpose of this study is to analyze how future development in Toronto's Central Area will affect street-level sun, wind, and thermal comfort conditions. The study stemmed from public concern about the quality of the downtown environment and is related to implementation measures under consideration for a new plan for Toronto's Central Area. This study continues the work presented in the 1974 document "Onbuildingdowntown," as well as work done by the Berkeley research team in San Francisco and New York City.

The research presented in this report examines the shadows produced by downtown buildings and recommends procedures and standards for preserving sunlight on Central Area sidewalks and open spaces. Secondly, this study considers the effects of buildings on wind conditions at street-level, and thirdly, the study evaluates the combined effects of sun and wind conditions on pedestrian comfort. Rather than focusing on just the effects of individual buildings, this research evaluates the cumulative effects of area wide development.

Lastly, the study illustrates the effect of future development on the visual qualities of Central Area streets. The study compares existing development conditions with development permissible under current planning controls and under the standards recommended in this report.

Study Areas and Study Procedure

In order to study the influence of building, street, and open space dimensions on sun, shade, wind, and comfort, the study team conducted field measurements and laboratory experiments within an area defined by the Canadian Pacific Railroad tracks to the north, the Lake to the south, Spadina to the West, and Sherbourne to the East. Three areas within the Central Area were selected for detailed laboratory experiment. These areas include:

1. The North Midtown area centered on Bloor and Bay Streets;
2. The East Downtown area between Dundas and Queen Streets, Yonge and Jarvis Streets; and
3. The Lakefront and Railway Lands centered on York Street between Union Station and the Lake.

A scale model was prepared for each of the three areas to represent existing building conditions. On sites where future development is likely to take place, two future scenarios were created. The first scenario illustrates development conditions under current planning controls. The second illustrates future development modified in ways assumed to reduce undesirable wind and shadow effects. This second scenario was constructed after a number of tests had been completed, including wind tunnel tests measuring the velocity of wind flows at a pedestrian level. The shading effects were determined by placing the models under a parallel-beam light source that was manipulated to reflect the sun's altitude and bearing angle at varying times of the day and year. To gauge the combined effects of measured wind and shadow conditions on pedestrian comfort, wind tunnel and shadow data was fed into a computer model that simulates the human thermoregulatory system. The model considers ambient temperature, humidity, wind velocity, and solar radiation, while making assumptions about activity level and the amount of clothing worn. The product of this model is a numerical ratio that expresses the percentage of time a particular place will be comfortable for outdoor users during daylight hours.

Additionally, field studies were conducted independently of the hypothetical development scenarios. Using photographic methods, the team recorded and mapped existing sunlight conditions in selected parks, squares, and plazas, and along selected Central Area streets.

Key Findings

The most basic observation confirmed by this study is that sunlight and wind conditions play a critical role for people in determining thermal comfort in public open spaces and along sidewalks.

Toronto has a climate with cold winters and hot, humid summers, but the cool-to-moderate conditions during the spring and fall provide comfortable conditions for pedestrians outdoors for many days of the year. During the winter, air temperatures are occasionally very cold and winds are frequently strong. Protecting pedestrians from building-induced wind conditions is an urgent concern. For park areas where people in protective winter clothing are engaged in recreation, sunlight present at midday will only have a mitigating effect on the climate when winds are calm.

From late April until mid-June, during Toronto's spring season, direct solar radiation plays a critical role for people in determining thermal comfort outdoors.

For people who want to sit outdoors on park benches, the combination of wind and ambient temperature conditions frequently make it too cool to sit in the shade. However, most of the park and plaza spaces studied are well enough sheltered from the wind that sitting in the sun is comfortable under most temperature conditions prevailing on spring days. To stay cool outdoors in the summer months many people seek shade and prefer a light breeze, especially on those days in August with high humidity. During these hot and humid times of the year, people find comfort on tree-shaded walks and in parks. Trees provide shade and, when planted in groups, may increase the buoyancy driven flow of air between the cooler tree-shaded areas and the warmer sunlit buildings and street surfaces.

During the fall season, climatic conditions are similar to those found in spring, although fall temperatures are somewhat warmer. In both seasons people sitting on benches or strolling leisurely along sidewalks benefit from direct sunlight and protection from wind.

In all three areas selected for this study, the analyses show that adverse wind conditions would be created in some locations given future development allowable under current planning controls. In general such conditions can be avoided if the height and placement of future building volumes are modified. The combined wind effect and shading caused by future development under current planning controls would render sections of sidewalks, and to a lesser extent park space, uncomfortable during the spring and fall seasons. Again, uncomfortable conditions could be avoided by scaling building dimensions in a way that allows sunlight to reach open spaces and sidewalks where people will stroll or play.

Recommendations

The findings in this report suggest the need for planning legislation that controls adverse wind conditions caused by new construction. In addition, this report recommends establishing height limits to preserve sunlight to parks and open spaces in the Central Area during those times of the day and year when sunlight is most needed for thermal comfort of pedestrians using open spaces for recreation.

This report recommends the use of sun access easements, so-called "solar fans," for the setting of zoning heights in the vicinity of open spaces. When drawn on maps, these easements take on the shape of a fan. The zones indicated by the leaves of these fans define building heights. Buildings built to these heights would not produce shadows beyond the extent of existing shadows. This report recommends permissible building heights in the vicinity of open spaces and the duration of time for which sunlight shall be preserved for each open space. These recommendations are specific for each type of open space in the Central Area.

Finally the report recommends that similar height limits be established to guarantee a minimum of three hours of sunlight encompassing the midday period on all streets in the Central Area, five hours of sunlight on streets where people stroll and shop, and seven hours of sunlight on residential streets lined by lowrise development.

The rationale for these standards are based on the climatic conditions in Toronto, and on field studies of current sunlight availability on Toronto streets. Our studies show the great majority of Toronto streets receive a minimum of three hours of sunlight during a period of time that encompasses midday at the spring and fall equinox. Many streets in the Central Area receive five hours and more during that same time of day and year.

This report makes four specific recommendations and demonstrates that these recommendations can be implemented primarily through zoning controls. Only a new code developed to protect sidewalks and open spaces from strong wind velocities should be implemented through a performance standard:

1. Review of the Zoning Height Districts

> **Revise the zoning height limits in the Central Area of Toronto. Set the revised height limits of each district compatible with density controls of the same district.**

Once established, the new zoning height limits should not be subject to discretionary review in negotiations between the sponsors of future development and the City of Toronto.

Recommendations 2 and 3 further modify the revised height limit:

2.Sunlight to Public Parks and Open Spaces

> **Restrict the allowable height of future development in the vicinity of publicly accessible open spaces in**

order to preserve sunlight during those time of year and day when it is most needed for the comfort of open space users.

Adopt an open space classification system that determines the duration of sunlight and extent of the open space area for which sunlight should be preserved.

3. *Sunlight for Streets*

Restrict the allowable height of future development to guarantee three or more hours of sunlight during a period encompassing midday along sidewalks of streets in the Central Area. Adopt a street classification system that classifies streets according to the amount of sunlight they shall receive at midday between the spring and fall equinox.

4. *Wind Protection*

Establish a performance standard that protects pedestrians from the mechanical force of winds induced by the design and placement of future buildings.

The standard should specify the testing procedures used to determine compliance, so that consistent results are obtained by different wind consultants when testing proposed projects. This standard should be developed under the oversight of a committee of City officials and the consultants in the Toronto region likely to be evaluating winds in the future. It is likely that the work will require the services of a contractor in assembling the weather data necessary for the standard.

In addition, it is suggested that the City consider undertaking further development work in conjunction with its wind consultants in order to create a standard incorporating the thermal influences of the wind on pedestrians as well as the mechanical influences.

Sunlight for Parks

Sunlight for Streets

Wind Protection

2. INTRODUCTION

Need for this Study

(excerpts from the February 1990 Terms of References)

The relationship of buildings to the spaces which adjoin them largely determines the quality of the public realm of the city, where streets and other open spaces provide the primary setting for public activity. Enjoyment of the outdoor environment can be significantly affected by microclimatic conditions and perceptual factors. Streets and other public open spaces which are sheltered from unpleasant wind conditions, which are sunny much of the day, provide amenity for the activities which sustain, enliven and enrich urban life.

In Toronto, as in many other North American cities, the rapid growth of the 1980s has been accompanied by mounting public concern about environmental quality.

At the same time technical advances have occurred which facilitate more accurate monitoring of microclimatic, visual and experiential effects in the urban environment, and that make it possible to identify more specific criteria for pedestrian comfort.

Purpose of this Study

The purpose of this study is to explore the relationship of building form to microclimate and pedestrian perception at street level, in order to establish standards that will ensure that building form contributes positively to the pedestrian environment, permitting adequate sunlight, comfortable wind conditions, and suitable scale relationships. This study examines microclimatic and perceptual variables affecting comfort levels for pedestrians on city streets and other public spaces. It defines controls for built form which ensure that comfort levels adequate for an appropriate range of pedestrian activities are met at all times, and that comfort levels are maximized during periods of peak pedestrian use.

Report Structure

The report begins with a generalized discussion of sun, wind, and scale in urban design and moves into a detailed explanation of the study method. Next, an analysis of the results is presented. The analysis section includes diagrams indicating the wind speeds and maps of each area relating comfort conditions to development intensity, location, and form. The report ends with generalized findings and recommendations.

Background for this Study

The City of Toronto is currently considering review and revision of its Official Plan policies on built form and environmental quality criteria. In recent years, a number of North American cities have introduced policies that value sunlight and protect street environments from adverse wind conditions. With its 1982 Midtown Development Controls, New York City reintroduced the 1916 standards for preserving daylight and the openness of street canyons to the sky. The revised planning standards in New York compare light conditions along avenues and streets of Manhattan under the historic 1916 district controls to conditions expected under new controls. Building forms and setbacks are calculated for anticipated light levels and a proposed Midtown building meets the standard if it permits a specified amount of daylight to reach the street level.

The methodology used in Manhattan was reviewed for its suitability in Toronto. Using the Manhatan methodology, existing ambient light levels for Toronto streets could be measured and the effect of future development on sunlight levels could be simulated. However, criteria for judging the acceptability of daylight standards would be arbitrary.

The 1986 San Francisco Downtown Plan includes standards for sun access to downtown streets, parks, plazas, and squares. Sun-access controls set limits on the height of buildings in the vicinity of parks and open spaces, buildings along streets in the retail district, and also along Market Street. Due to San Francisco's cool windy climate, direct sunlight and shelter from wind are necessary for a comfortable street environment. In 1984, the citizens of San Francisco voted to amend the city charter with an ordinance that protects sunlight on city-owned parks and squares from one hour after sunrise to one hour before sunset for all months of the year.

In 1984, the City of San Francisco developed a wind ordinance for the downtown districts and established guidelines for compliance. A section of the San Francisco Downtown Plan implemented by the Planning Commission in 1989 requires new buildings to be shaped or sited in such a manner that ground level wind limits for seating 11 km/hr (7 mph) and pedestrian areas 18 km/hr (11 mph) are not exceeded during more than 10 percent of daylight hours.

The challenge of this present study has been in developing planning controls that integrate standards for a comfortable microclimate on sidewalks and in other public open spaces with existing standards for land use and urban design. Standards under consideration include: density controls; height and bulk regulations and setback rules; landscape planning; and maintenance of street trees in the public right of way and other open spaces.

The 1974 consultant study, "Onbuildingdowntown," commissioned by the City of Toronto Planning and Development Department, was explicit in stating objectives that the form of new buildings should create desirable year-round conditions of sun and shade in (a) designated open spaces; (b) surrounding streets for pedestrians and vehicles; and (c) surrounding residential buildings.

The objectives led to requirements for designated open spaces, as follows:

(i) Design new buildings so as to maximize the extent to which direct sunlight reaches designated open spaces, (at 9:18 a.m., 12:18 p.m., and 3:18 p.m.) on the spring equinox, March 21, and on the autumn equinox, September 21 (E.S.T. and D.S.T.)

Requirements for streets were as follows:

(i) Design new buildings so as to minimize the extent to which those buildings overshadow the north sidewalks of east-west streets at 12:18 p.m., on the spring equinox, March 21, and on the autumn equinox, September 21 (E.S.T. and D.S.T.);

(ii) Design new buildings so as to minimize the extent to which those buildings overshadow the west sidewalks of north-south streets at 9:18 a.m. on the spring equinox, March 21, and on the autumn equinox, September 21 (E.S.T. and D.S.T.); and

(iii) Design new buildings so as to minimize the extent to which those buildings overshadow the east sidewalks of north-south streets at 3:18 p.m. on the spring equinox, March 21, and on the autumn equinox, September 21 (E.S.T. and D.S.T.).

The study also gave a number of precedents of buildings that were considered examples for achieving the stated principles.

With regard to wind and calm, "Onbuildingdowntown" states the following goals:

(i) To ensure that new buildings do not aggravate existing daily wind conditions in such ways as to either increase the wind velocity to undesirable levels or to deflect it from places where it would be desirable.

(ii) To provide open spaces that are places of calm, sheltered from the wind.

A number of requirements for boundary layer wind tunnel testing were then defined by the study, which apply to selected projects over a specified height limit in the Central Area at the discretion of the Planning Department. Such testing has been carried out for most major projects erected during the tenure of the 1976 Official Plan.

The objectives of "Onbuildingdowntown" were subsequently incorporated in the Official Plan. However, here the detailed requirements pertaining to public streets have become part of two generalized statements:

1A, 41(a) It is the policy of Council to encourage the retention, development, and enhancement of public streets and streetscapes which have well defined character, scale and enclosure, to ensure that they are comfortable and convenient and offer varied activities and experience to pedestrians.

1A, 48 In order to achieve an improved pedestrian environment at and around street level in the Central Area, Council will seek to ensure satisfactory conditions with respect to wind and calm, and sun and shade. In doing so Council will seek to alleviate existing problems of high wind velocities and lack of sun in important pedestrian areas caused by the height or inappropriate spacing or configuration of buildings, and to prevent the worsening of such conditions. In using its power of regulation and review in implementing this Section, Council will apply objective standards to determine satisfactory conditions.

Fifteen years after the adoption of the Official Plan, we can judge its effectiveness where a number of new buildings have been designed in accordance with these objectives. It is now quite evident that the intended results have not always been achieved on the streets and open spaces of the Central Area of Toronto.

The reason for this is twofold. First of all, the language used for describing the requirements was vague; for example, the design should "minimize the extent to which the new building overshadows the sidewalks" and "maximize the extent to which direct sunlight reaches designated open spaces." The language leaves much to interpretation and was not clearly enough defined to permit strict enforcement of the Official Plan.

Secondly, at the time of the adoption of the Official Plan, it was hoped that specific language for implementation would follow. Specific planning controls were never legislated. Section 40, the site plan review process, was the only legal instrument available for implementing the above stated objectives, but proved to be insufficient.

Also, some requirements in "Onbuildingdowntown" were demanding and probably not achievable within a densely developed urban core; for example, achieving "sunlight on a west sidewalk on a north-south street at 9:18 in the morning on the autumn equinox." Here, a building could only be half as high as the width of the street. In other words, on a 26m wide street such as Bay Street, a building could be only 12m high at the lot line. This recommendation is very restrictive indeed.

As a result, the requirements were largely ignored, and although it was requested that wind tunnel tests and sun/shade studies be provided for selected developments, these tests were used for negotiation purposes only. City officials lacked specific standards for enforcement, and consequently, the authority to demand the desired sun penetration and comfort amenities for streets and open spaces.

The main body of the report starts with a discussion of the relationship between climate and urban form and continues with definitions of Toronto's climate, reports on the field studies, and the testing of alternative levels of future development under laboratory conditions, and concludes with recommendations for planning controls with guidelines for compliance.

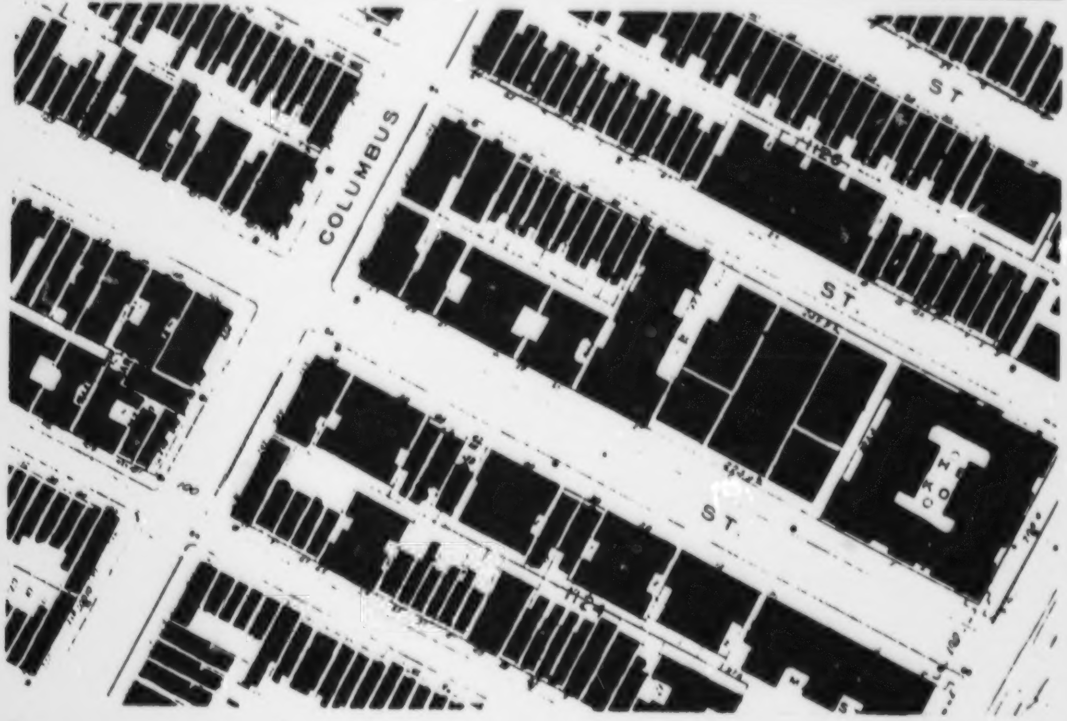
Sun, Wind, Comfort, and Scale in Urban Design

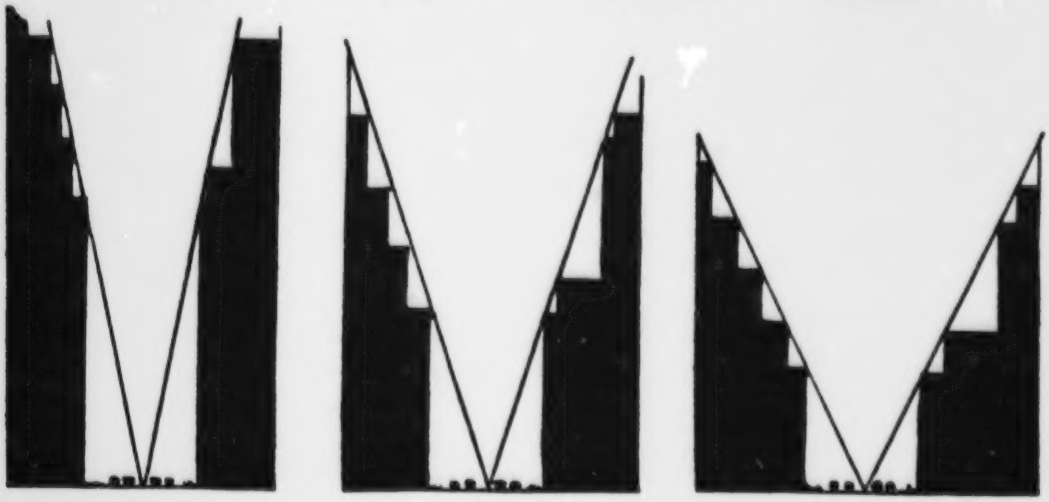
The form of cities emerges over time and is shaped by decisions about the construction and demolition of physical structures. The form emerges in predictable ways, although these decisions are made at different times by people without obvious connections. Despite the great variety of a city, we find many similarities between streets, districts, and building types.

These similarities are not accidental. They are the result of an elaborate system of rules that contribute to a collective understanding about the design of cities. At its most basic level, this understanding supports a social system in which things are encouraged or discouraged through essentially social means, ranging from legal sanctions to the most subtle incentives.

One such rule is the right to light and air in city streets and open spaces. Limits on the height and bulk of buildings have existed as a legal embodiment of good neighborliness in order to promote public health and comfort. In fact, such rules on height and bulk became the basis for zoning ordinances in Canada and elsewhere.

In North America, the first study that led up to this subject was conducted in 1913 by the Commission on Heights of Buildings of New York City. The commission was an investigating body appointed by the Board of Estimate and Apportionment to study how skyscrapers affect the safety and health of the community. If the commission discovered an effect, it was to indicate what regulation could be lawfully adopted to bring improvement. When the committee was formed in the beginning of 1913, any office or hotel structure in New York City could cover an entire site, rise to any height, and maintain the lot dimensions at the highest story. Shadows cast from high-rise structures darkened streets and build-





"A"
"The heighest degree"

"B"
The "middle" degree

"C"
The "lowest" degree

Fig 2.1 Map of the Upper West Side of Manhattan.

The wide streets, or avenues, measure a hundred feet in width, allowing building heights of one and a half times the width of the avenue (30m or 100 feet). Above that height, buildings must recede as they ascend within a line drawn from the center of the street through the top of the wall under the lot line. The side streets measure 20m (65 feet) in width, allowing 20m (65-foot) building heights equal to the width. Above that height, as on the avenues, buildings ascend within a line drawn from the center of the street through the top of the wall upon the lot line.

ings. The Commission recommended that building heights and use be regulated (in the interest of public health and safety). The report resulted in an amendment to the city charter including height and use districts under the provisions of the Board of Estimate and Apportionment. The law has been in operation since it was passed on July 25, 1916. The new charter amendment came at a time when districts were expanding rapidly on the Upper East, and more recently the Upper West, sides of Manhattan. The new height rules have given these districts and others a very distinctive form and character *(Fig. 2.1)*.

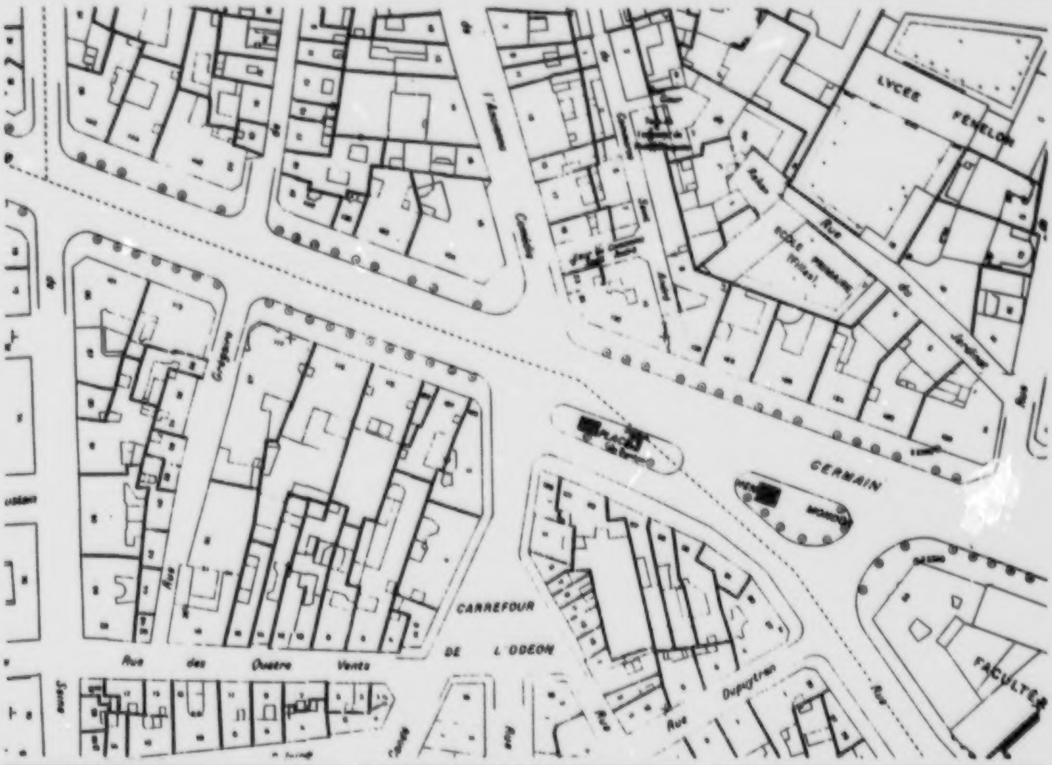
The Commission that framed the New York City charter amendment had made a careful study of building regulations in European cities. In Paris, for example, the King's declaration on Building Lines and Window Openings, dated April 10, 1783, was followed by an ordinance on August 25, 1784, defining the major principles of regulating architecture. These principles set a cornice line, slope of roof, and calculated facade height as a function of the street's width. The standards were somewhat arbitrarily chosen. On streets between 9.75 and 20 meters in width, the maximum height was set at 17.54 meters with roof sloping upwards at 45 degrees. In the hundred and fifty years following, these height limits were modified, in 1869, 1884, and again in 1902, eleven years prior to the visit by New York planners *(Fig. 2.2)*.

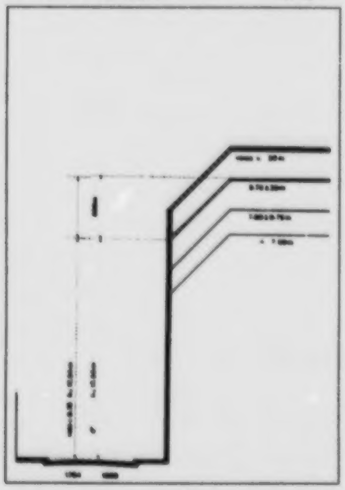
The use of the mansard roofs along most streets built during the Haussmann period strongly characterized the skyline of Paris after 1884. When the commissioners from New York examined the 1902 revisions to the Parisian buildings laws, they found that the height limits maintained the height of the street facade at 18 meters (the earlier limits had been 17.54 meters in 1784), but increased the total allowable height to 30 meters.

In Paris, situated at 47 degrees northern latitude, a 49-degree slope of a roof would allow sunlight to reach into north-south streets of 20m width between 11:00 a.m. and 1:00 p.m. from April 2 to September 10. In New York City, located further south at 39 degrees north latitude, the altitude of the sun exceeds 45 degrees more frequently during daylight hours in the course of the year, giving a greater percentage of sun to streets of 20m width. Indeed, the setting of such angles and building heights appears somewhat arbitrary, given the various width of streets, their orientation, and the location of a city with regard to the position of the sun and climatic zone.

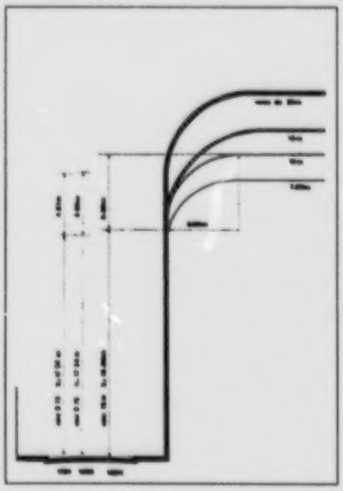
Sun, Wind, and Comfort

Although the relationships between the overall form of a city and its climate can be intuitively understood, it is generally not possible to use intuition for predicting how specific future buildings will affect climatic conditions. Also, there is no comprehensive mathematical model that can predict the effects of proposed structures on the comfort of those who walk along sidewalks or use public open spaces. By comfort here, we mean the physiological well being of a person leisurely walking along a sidewalk or sitting on a bench outdoors. A combination of experimental and computational techniques is necessary to make such comfort predictions. For example, the amount of shadow a future building will cast on sidewalks and open spaces can be measured by placing scale models into an artificial sky-laboratory where the

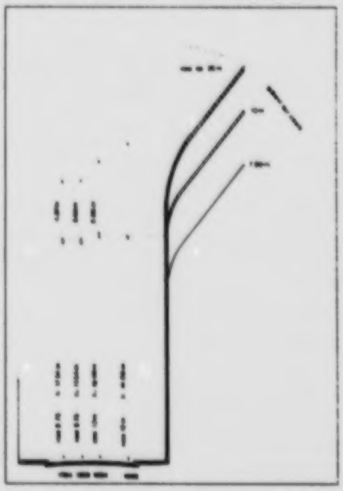




1. A diagram of the 1859 regulation on building height. Courtesy of the Atelier Parisien d'Urbanisme. On streets over twenty meters wide, cornice height was raised 2.5 meters, which made apartment buildings look much more monumental.



A diagram showing how the 1884 regulation affected building height.
By authorizing roofs that fit under an arc with a radius of six meters, the 1884 regulation resulted in larger roof volumes; cornice height, however, did not change. Diagram courtesy of the Atelier Parisien d'Urbanisme.



A diagram showing how the 1902 building code affected building height.
The 1902 regulation on building height was the most generous in the city's history. While cornice height remained the same, roof volume was determined by an arc whose radius, varying according to street width, was extended by a 45-degree diagonal. Maximum building height thus rose to 32 meters (compared to 22.41 meters in 1784). Diagram courtesy of the Atelier Parisien d'Urbanisme.

Fig. 2.2 Map of the Blvd. St. Germaine, Paris. Diagram of regulation on building height. Prepared by Atelier Parisien d'Urbanisme

sun is represented by a parallel-beam light source. The light source can be adjusted to represent the altitude and direction of the sun at any given time. The extent of the shadows over selected times of the year is then measured inside the scale model. Sun and shadow analysis can also be performed by computer using a three-dimensional data file of all building, street, and open space dimensions, combined with software for shadow casting, shadow accounting, and modeling of proposed buildings.

Similarly, in most complex cases, the airflow around buildings must be measured against a scale model of existing physical conditions placed in a boundary-layer-simulating wind tunnel. By inserting models of proposed or potential future development in the tunnel, accurate measurements of street level wind velocity, direction, and turbulence can be obtained. Building-induced wind phenomena can be obtained through comparing measurements under existing conditions with measurements of changed conditions.

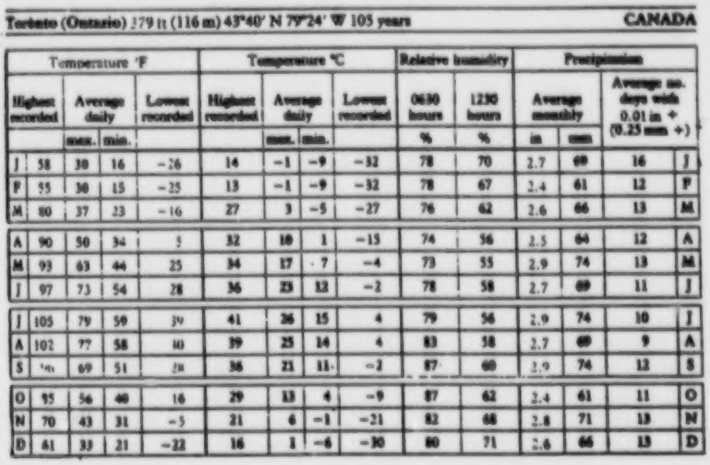
The measurements of **wind** and **sun** or shadow conditions provide two of the six key variables that affect human comfort. **Solar radiation** provides warmth for the human thermoregulatory system. A human body exposed to wind exchanges body heat through convection. Two other climate variables, **humidity** and **ambient air temperature**, also affect thermal comfort. Values for these are usually obtained from weather records. In addition, the model must know or make informed assumptions about the activity levels of people and the amount of clothing worn. In recent years researchers have attempted to establish computer modeling procedures that predict the combined effect of these six comfort-influencing variables. Although such computer techniques show promise and work reasonably well for predicting comfort conditions in indoor environments, they are still unpredictable with regard to climatic conditions outdoors. They may be used, however, to predict relative spatial and temporal comfort under alternative development scenarios outdoors (See Arens and Bosselmann, 1989; Bosselmann et al., and Arens et al., 1984)

A combination of wind tunnel simulation, sun access analysis, and mathematical modeling of the human body's thermoregulatory system under Toronto's climatic conditions have been used in the laboratory studies of this report. These methodologies are explained in detail in section 3.2.3 of this report.

Climate and Comfort in Toronto

Human beings of any age and sex have limits of heat loss above which they both feel cold and are indeed being physiologically impaired. Similarly, major discomfort and some distress does occur on certain summer days when temperature rises above 30 degrees Celsius and the relative humidity measures 60 percent at midday. Canadians face challenges from natural climate in a greater measure than people in most other countries. Together with the people in most parts of the Soviet Union, Canadians experience both humid heat in the summer and harsh cold in the winter.

Toronto, located at 43 degrees 40' northern latitude and 79 degrees 24' west of Greenwich, has a cold winter season, a cool spring, a hot sometimes humid summer, and a cool fall season *(Fig. 2.3)*. Winter in Toronto lasts from November



Toronto (Ontario) 379 ft (116 m) 43°40' N 79°24' W 105 years **CANADA**

	Temperature °F				Temperature °C				Relative humidity		Precipitation			
	Highest recorded	Average daily		Lowest recorded	Highest recorded	Average daily		Lowest recorded	0630 hours	1230 hours	Average monthly		Average no. days with 0.01 in + (0.25 mm +)	
		max.	min.			max.	min.		%	%	in	mm		
J	58	30	16	−26	14	−1	−9	−32	78	70	2.7	69	16	J
F	55	30	15	−25	13	−1	−9	−32	78	67	2.4	61	12	F
M	80	37	23	−16	27	3	−5	−27	76	62	2.6	66	13	M
A	90	50	34	5	32	10	1	−15	74	56	2.5	64	12	A
M	93	63	44	25	34	17	7	−4	73	55	2.9	74	13	M
J	97	73	54	28	36	23	12	−2	78	58	2.7	69	11	J
J	105	79	59	39	41	26	15	4	79	56	2.9	74	10	J
A	102	77	58	40	39	25	14	4	83	58	2.7	69	9	A
S	[illegible]	69	51	28	38	21	11	−2	87	60	2.9	74	12	S
O	95	56	40	16	29	13	4	−9	87	62	2.4	61	11	O
N	70	43	31	−5	21	6	−1	−21	82	68	2.8	71	13	N
D	61	33	21	−22	16	1	−6	−30	80	71	2.6	66	13	D

Fig 2.3 Toronto Climate Data (Source:The Times Books World Weather Guide, 1984)

to March or April. During these six months the mean daily temperatures range from 4.8 degrees in November to 4.4 Celsius in January.

Spring comes to Toronto with some delay compared to cities located on the same northern latitude in Europe and Asia. During May and June, daily temperatures reach a mean of 13.2 to 19.2 degrees Celsius.

Summer in Toronto is warm to hot and sometimes humid. Temperatures in July and August measure around 21.2 degrees Celsius at the daily mean. The fall season in Toronto is somewhat warmer than the spring. Temperatures have a daily mean of 11 degrees to 11.2 degrees Celsius. The average daily maximum ranges from 21 degrees in September to 13 degrees Celsius in October.

Toronto's temperature and humidity condition are summarized in Fig. 2.3, and they are also shown in the bioclimatic chart, Fig. 2.4. This chart shows lines in the lower-right portion of the figure that indicate the range of the abovementioned monthly average maximum and minimum temperature and humidity conditions. In the middle of the chart, the shaded area indicates those temperature and humidity conditions under which a person leisurely walking, dressed in typical business clothing, would be comfortable in the shade.

For most of the year, Toronto's temperature makes such leisurely strolling uncomfortable. Only during July and August and on a few days in September will pedestrians be comfortable in the shade. The rest of the year the air temperatures are generally too low; direct sunlight is needed for comfort at this typical clothing level. The amount of radiation required to compensate for low air temperature is indicated by the lines below the lower edge of the comfort zone.

For example, to compensate for the cool midday temperatures of 10 degrees on a day in April, the equivalent of 350 watts per square meter of insolation (measured on the horizontal) are needed.

Direct sunlight will produce such amounts of radiation when the sun rises

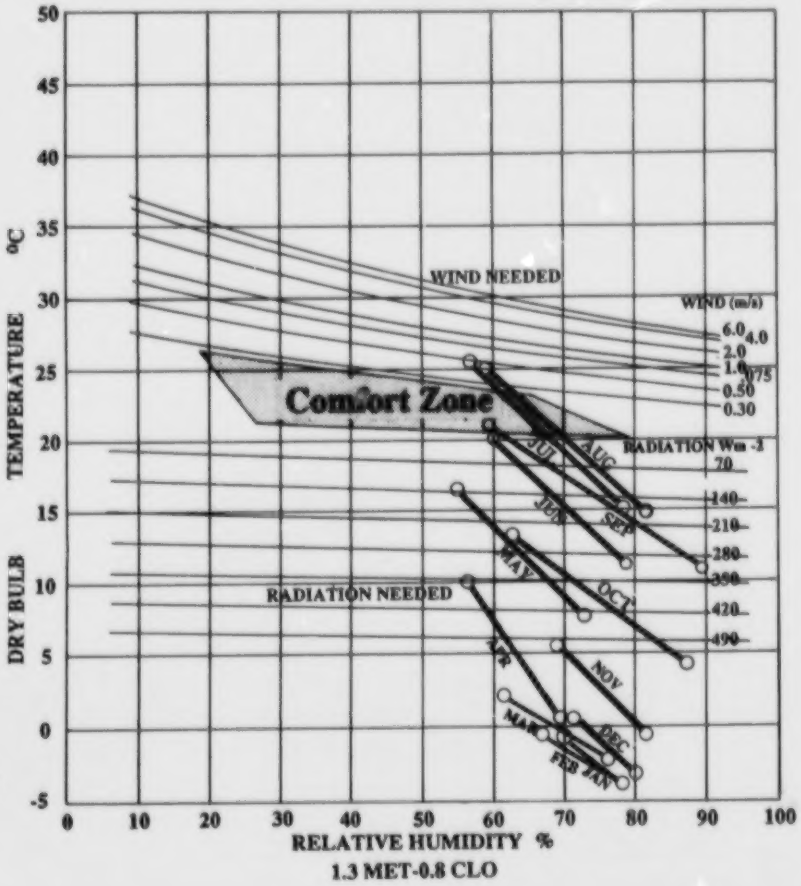


Fig 2.4 Bioclimatic Chart (Source: Center for Environmental Design Research 1990, Bureau of Standards, US Dept. of Commerce)

high enough above the horizon. In Toronto, the sun reaches sufficient altitude at midday in April and September. Prior to April when the sun is lower and air temperatures are even lower than 7 degrees Celsius, radiation from the sun alone will not suffice in producing comfortable conditions unless additional layers of clothing are worn. During the coldest times of the year, special insulating clothing is necessary to protect from even colder temperatures and from the chill of the winds.

During May and June and during September and October, pedestrians can expect comfortable conditions on those Toronto sidewalks and in parks that are sunny. In July and August, temperatures at midday rise above 25 degrees; on such days when the humidity measures above 55 percent people in Toronto will seek shade, reduce the amount of clothing, and ideally expose themselves to a light breeze in order to stay cool. They find such outdoor conditions at the lakefront or in one of the parks under trees.

The amount of wind needed to compen-

FIG. 2.5

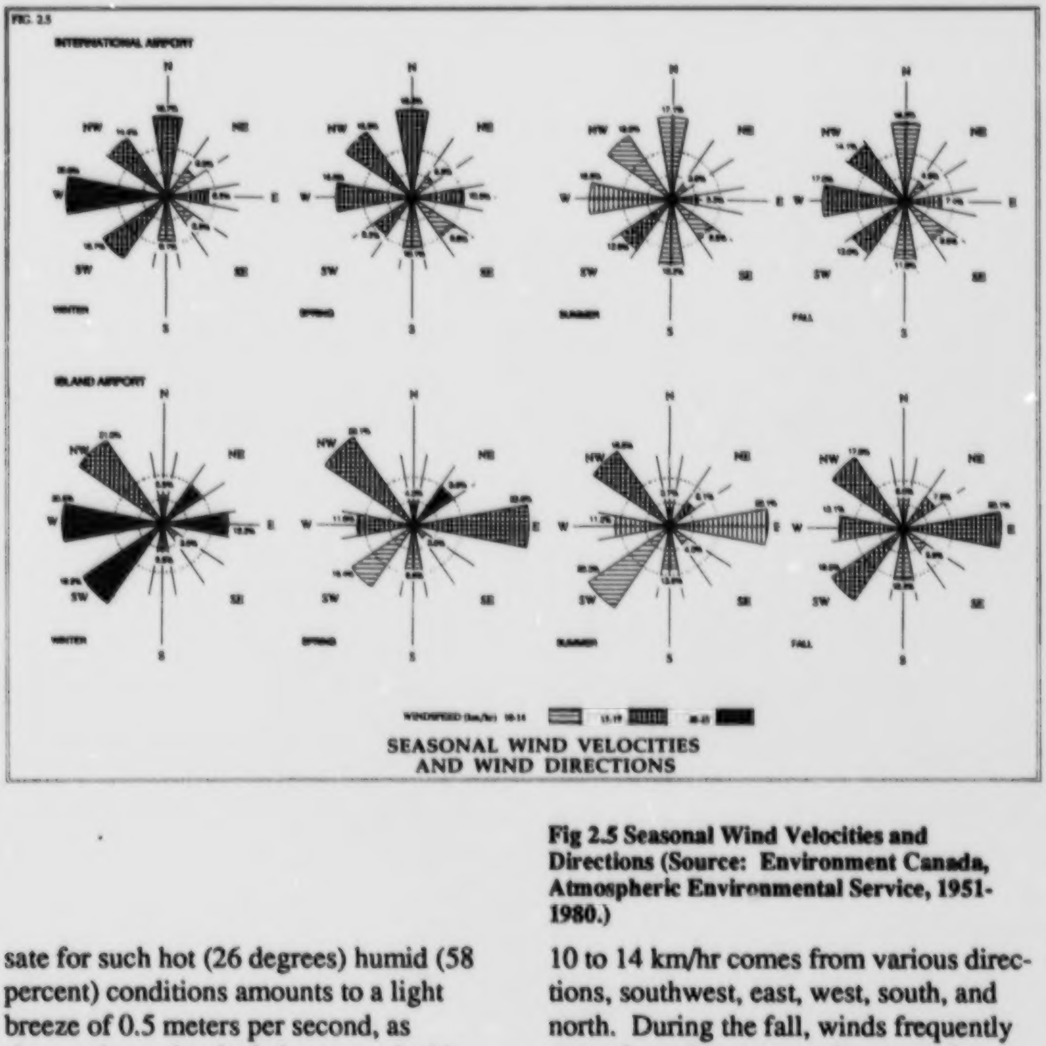


Fig 2.5 Seasonal Wind Velocities and Directions (Source: Environment Canada, Atmospheric Environmental Service, 1951-1980.)

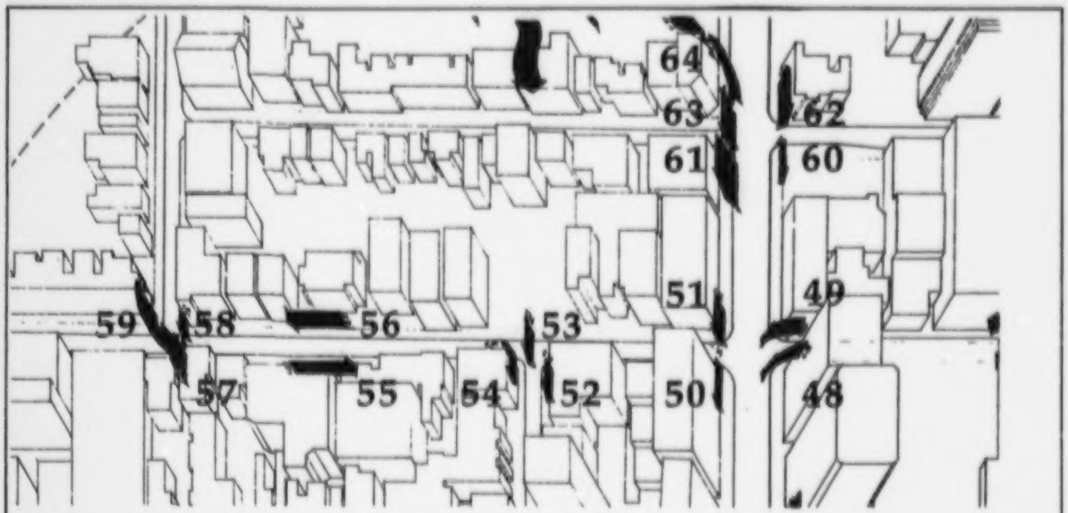
sate for such hot (26 degrees) humid (58 percent) conditions amounts to a light breeze of 0.5 meters per second, as shown above the shaded area on the bioclimatic chart.

Winds in Toronto

The winds are strongest in Toronto during the winter. They frequently exceed 20 km/hr from the west, southwest, east, and northeast. Such strong wind velocities are less frequent during the rest of the year. During the spring, the winds come from the northwest or east and have a strength of 15 to 19 km/hr. In the summer, winds are generally calmer. If strong, between 15 to 19 km/hr, they come from the northwest. Wind at 10 to 14 km/hr comes from various directions, southwest, east, west, south, and north. During the fall, winds frequently come from the east, southwest, and northwest at speeds of 15 to 19 km/hr (see Fig. 2.5, Seasonal Wind Velocities and Wind Directions).

Winds in Toronto Streets and Open Spaces

The measurements shown in Fig. 2.5 indicate data gathered at two Toronto locations -- the Island Airport and the International Airport. In both cases, the instruments are located in the vicinity of an open air field at a height of 10m. The comparison of these measurements shows considerable differences between



Pt. No.	Wind Ratio NW	W	SW	E
48	0.418	0.395	0.241	0.362
49	0.361	0.317	0.59	0.351
50	0.336	0.595	0.521	0.397
51	0.423	0.505	0.481	0.422
52	0.311	0.372	0.592	0.411
53	0.382	0.529	0.55	0.298
54	0.294	0.324	0.307	0.251
55	0.234	0.533	0.335	0.403
56	0.424	0.496	0.361	0.369
57	0.55	0.666	0.263	0.383
58	0.362	0.673	0.444	0.594
59	0.811	0.604	0.363	0.254
60	0.244	0.622	0.573	0.43
61	0.916	0.686	0.56	0.349
62	0.396	0.49	0.32	0.491
63	0.596	0.564	0.416	0.345
64	0.598	0.715	0.493	0.538

Fig 2.6 Map showing wind velocity ratios for Northwest wind in the Yorkville area of Toronto, and tables indicating wind velocities for West, Southwest and East winds.

the two locations. Explanations for these differences are found in the fact that the City of Toronto as a concentration of buildings affects the flow of the wind. For example, north winds, frequent and strong at the International Airport, are rarely measured at the Island Airport weather station. Here the proximity of concentration of high buildings to the north of the airport in downtown Toronto shelters the station from such winds. Similarly the east winds reach the Island station along the shores of Lake Ontario unobstructed. The same wind will not measure as frequently and as strongly at the International Airport, which is sheltered from these easterly winds by the City of Toronto.

Winds on Toronto Streets

At a smaller scale, the winds along Toronto city streets and in open spaces differ greatly in direction and velocity when compared with the measurements at the stations. Here, wind velocities at street level are reduced or sometimes accelerated, depending on a number of variables such as the presence of buildings in the vicinity, and their height and shape, the dimension and direction of streets and open spaces. Generally, the buildings in an urban area shelter streets and open spaces from weather-induced winds. For example, on Yorkville Avenue near Bel Air Street in a section of Toronto's Central Area, where low buildings line narrow streets, the velocity of the wind will only measure 25 percent to 50 percent of the wind velocity at the weather

Pt. No.	Wind Ratio NW	W	SW	E
1	1.088	1.163	0.149	0.898
2	0.385	0.998	0.228	1.091
3	1.105	0.617	0.253	0.52
4	1.495	1.206	0.324	0.877
5	0.941	0.832	0.206	0.441
6	1.276	0.787	0.318	0.691
7	0.768	0.661	0.354	0.704
8	0.949	0.639	0.318	0.652
9	0.775	0.526	0.41	0.716

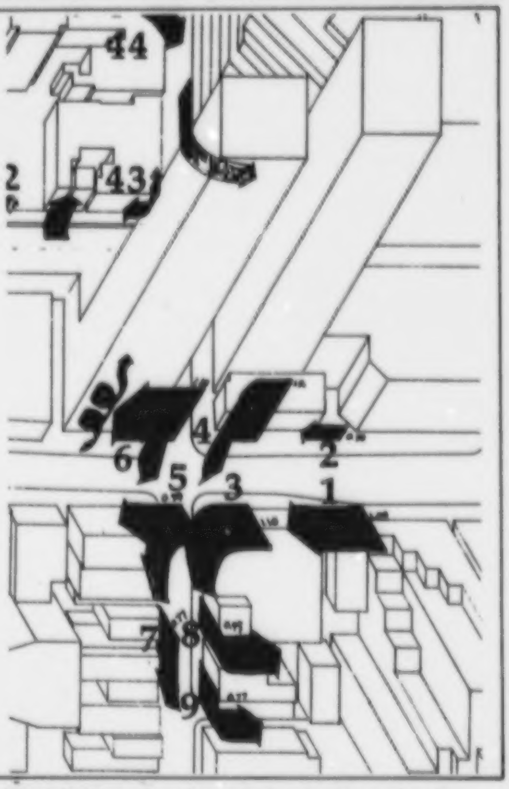


Fig 2.7 Map showing wind velocity ratios for Northwest wind at the intersection of Bloor and Yonge Streets, and table indicating wind velocities for West, Southwest and East winds.

station.

The results shown on Fig. 2.6 are the results of wind tunnel simulations described in detail in Section 4 of this report.

As an example for accelerated wind velocities, the map in Fig. 2.7 shows how the placing and height of two tall buildings increases the wind velocities at the intersection of Bloor and Yonge Streets. Here the velocity of the wind at the foot of these buildings and across the street is equal or greater to the speed at the weather station. The velocities measured range from 94 percent to 150 percent of the speed measured at the station on days with northwest winds.

It is important to note in studying these results that within a few blocks distance wind speed is modified by the form of buildings to measure between 25% and 150% of the windspeed measured at the weather station.

The Effects of the Mechanical Force of the Wind

Apart from the wind's cooling effect at warm temperatures and the chilling effect at low temperatures, the human body is subjected to the mechanical force of the wind. The effects of the mechanical force of the wind on pedestrians has been tested empirically and is described

WIND EFFECTS

Wind Speed	Effects Observed and Deduced
0	Calm, no noticeable wind
	Wind felt on face
7.1	Clothing flaps
14.2	Newspaper reading becomes difficult
21.3	Hair disarranged, dust and paper raised, rain and sleet driven
28.3	Control of walking begins to be impaired
	Violent flapping of clothes, progress into wind slightly slowed
35.4	Umbrella used with difficulty
42.5	Blown sideways, inconvenience felt walking into wind, hair blown straight
	Difficult to walk steadily, appreciably slowed into wind
	Noise on ears unpleasant
49.6	Generally impedes progress
	Almost halted into wind, uncontrolled tottering downwind
56.7	Difficulty with balance in gusts
	Unbalanced, grabbing at supports
67.3	People blown over in gusts
78.6	Cannot stand

Standard equivalent mean wind speed in kilometers per hour

Fig 2.8 Wind Effects. Source: Edward Arens, Designing for an Acceptable Wind Environment (1981).

in Fig. 2.8 (Arens, 1981). The wind-speed limits ('acceptability criteria') are expressed in terms of an "equivalent wind," combining the effects of mean windspeed and wind turbulence or gustiness on people (Hunt, 1976; Jackson, 1978). The acceptability criterion for seating areas is 12 km/hr (7 mph) or 3.1 m/s equivalent windspeed. At this velocity a newspaper flaps and is difficult to read.

The acceptability criterion for areas where people walk is 18 km/hr (11 mph). The support for this criterion is based on the original 5 m/s (11 mph) limit used by Penwarden and Wise (1973), Hunt (1976), Melbourne (1978), and others. At this velocity hair is unpleasantly disarranged, rain is driven laterally, and dust and paper are raised. Both of these comfort criteria are close to those proposed originally by Davenport (1972).

Finally, the criterion for safety is exceeded when gusts of wind exceed 70 km/hr (44mph, 20m/s). At this wind velocity people have serious difficulty with walking and elderly persons may be blown over. Although this velocity is a commonly accepted limit for people's safety, there are differences among wind researchers on how often it should be allowed to be exceeded in a standard.

Sunlight on Toronto Streets

The natural phenomenon of sunlight is frequently taken for granted. We understand that the sun traverses the sky from east to west at angles that are higher or lower depending on the time of day and year. While this understanding reflects accurately our observations, we know that matters are a great deal more complicated. The earth travels around the sun, and at the same time rotates around its own axis. The calculation of the earth's position at a moment in time is therefore a complex geometric task. This computation is explained in Appendix I of this report. The appendix also includes a table of sun angles at important times of day and year. For the understanding of this report, it is important to have some detailed knowledge of sun angles and the orientation of Toronto streets.

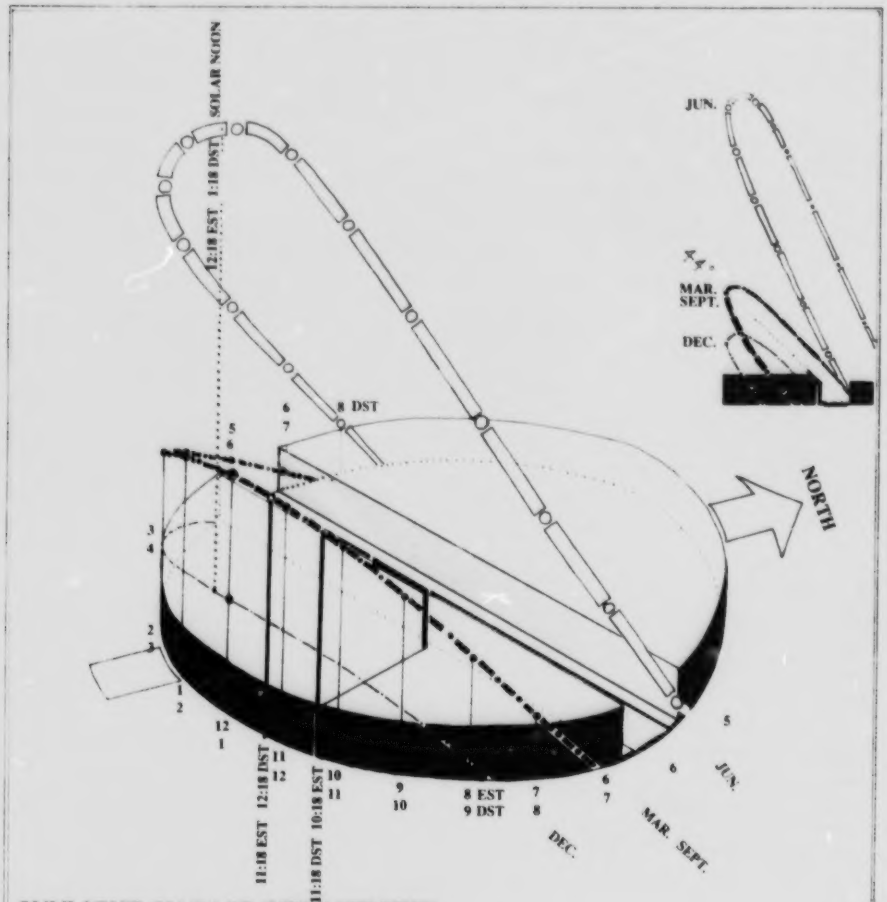
The Toronto street grid is rotated by sixteen to eighteen degrees to the west of north. The two diagrams, Fig. 2.9 and Fig. 2.10, explain the relationship of the sun's arc in June, September , March, and December (Fig. 2.9 for east-west and Fig. 2.10 for north-south streets).

Sunlight for East-west Streets

Following the sun's arc in September and March, buildings on the southside of an east-west street prevent sunlight from reaching the street- at sunrise. Not until midmorning when the sun has risen to an altitude of, for example, 37 degrees, will sunlight reach the northern sidewalk (assuming a building height of less than 12m on the southside of the street, and a street width of 20m). With higher buildings or narrower streets, sunlight would reach the northern sidewalk at a time close to noon, but only if the relationship of building height to street width does not exceed a ratio of 1:1. If such a ratio is exceeded, sunlight will not reach the northern sidewalk by noon between the month of September to March. In order for the December sun to reach the northern sidewalk by noon, a building could not exceed 8m in height at the property line of a 20-meter-wide street. In June, however, a 60-meter-high building would allow sunlight on the northern sidewalk at noontime.

The term noontime indicates a moment in time when the sun is at the highest position in the sky on a given day. This moment in time is referred to as solar noon. In Toronto this time does not exactly correspond to noon local Eastern Standard (EST) time, but to 18 minutes after the noon hour from late October to late April and 1:18 PM Daylight Savings Time from late April to late October. (The computation of solar noon takes into consideration the distance between the longitude of Toronto at -- for example -- City Hall to the meridian of the Eastern Standard Time zone. In addition, an exact computation would consider the velocity at which the earth travels on its elliptical orbit, and a factor for the refraction of sunlight upon entry into the earth atmosphere. The exact computation would show a slightly different time of solar noon for each month. The exact hours can be found in the sun angle table in appendix I.)

Prior to solar noon, the sun is positioned on an axis that is exactly perpendicular to east-west streets (or directly in line with north-south streets). In March this position is reached at


SOLAR NOON
12:18 EST 1:18 DST
8 DST
6
7
5
6
3
4
2
3
1
2
12
1
11:18 EST 12:18 DST
11
12
11:18 DST 10:18 EST
10
11
9
10
8 EST
9 DST
7
8
6
7
6
5
JUN.
MAR. SEPT.
DEC.
NORTH
JUN.
MAR.
SEPT.
DEC.

SUNLIGHT ON EAST-WEST STREETS

Fig 2.9

11:30 a.m. EST, in September at 12:30 p.m. DST, in June shortly after 12:45 p.m. DST, and in December at 11:00 a.m. EST.

In the afternoon, the sun is positioned in the western sky above the axis of east-west streets. This position is reached at 4:00 p.m. DST, in June, at 4:45 p.m. EST, in March, and at 5:30 p.m. DST, in September. In December the sun sets below the horizon at a time prior to reaching the axis of an east-west street.

In summary, the northern sidewalk on an east-west street with buildings on the south side that measure in height 0.8 times the width of the street will receive no sunlight in December, approximately five and a half-hours starting at 12:18 p.m. DST in September (11:18 a.m. EST in March), lasting until a time shortly before sunset. In June the same sidewalk would be in the sun most of the day except for the early evening hours prior to sunset.

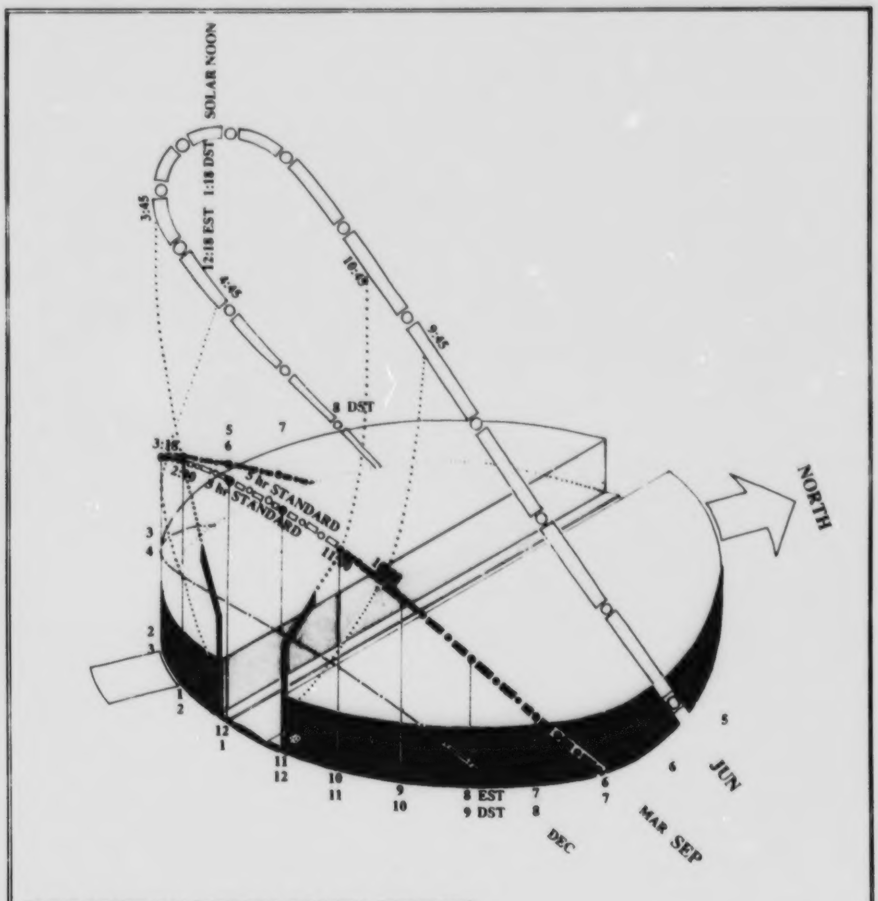

SOLAR NOON
12:18 EST 1:18 DST
3:45
4:45
10:45
9:45
8 DST
5
6
7
3:18
2:30
3 hr STANDARD
5 hr STANDARD
11
NORTH
3
4
2
3
1
2
12
1
11
12
10
11
9
10
8 EST
9 DST
7
8
6
7
6
5
JUN
MAR SEP
DEC

Fig 2.10

SUNLIGHT ON NORTH-SOUTH STREETS

Sunlight on North-South Streets

The sun located in the southern sky shines along the axis of north-south streets for a period of time during midday. In December, this position occurs shortly after 11:00 a.m. EST; in March, half an hour later at 11:30 a.m. EST; in June, as late as 12:45 a.m. DST; and in September at 12:30 p.m. DST. Sunlight reaches first the western sidewalk, then both sidewalks at the times indicated above, and finally only the eastern sidewalk. In March and September, this window of time lasts approximately three hours on streets where the height of buildings measures 1.5 times the width of the streets, or five hours, where the height of buildings measure 0.8 times the width of streets. In the summer these windows of time are longer (3 hours become 4.5 hrs.), in December shorter (3 hours become 1.5 hrs.).

Criteria for Establishing a Sun Access Standard

The discussion on Toronto's climate concluded that sunlight is essential for pedestrian comfort during the spring and fall, especially at those times of day when radiation from the sun is capable of compensating for cool air temperatures. Therefore, in the spring and fall, a period of time encompassing noon is at a premium for pedestrian comfort on Toronto streets.

The second criterion for a sun access standard takes into consideration use and activities on Toronto streets. Lunchtime for office workers varies somewhat between 11:00 a.m. and 1:00 p.m. local time regardless of Eastern Standard Time or Daylight Savings Time.

Surveys in other cities have indicated that office workers take 30-minute to 60-minute lunch breaks, and rarely walk to locations that are further than three city blocks from their place of work. A minimum standard for sunlight to streets would need to consider a two-hour period for a time when, ideally, all streets in Toronto should have at least one sunny sidewalk. For north-south streets, such a period would start at 11:00 a.m., and would last until 1:00 p.m. Given the shift of time from EST to DST in late April, 11:00 a.m. EST would become 12:00 p.m. DST, and 1:00 p.m. would become 2:00 p.m.. The effect of this shift would be a three-hour time window from 11 a.m. to 2 p.m. DST, set for the 21st of September. While such a window of time would serve office workers at lunch time, a more extensive time window should be considered to benefit shoppers on commercial streets and residents on neighborhood streets, especially children and elderly people who use sidewalks for extended periods of time. A five-, or even a seven-hour, time window of sunlight would provide residents with comfortable climatic conditions from mid-morning to mid-afternoon.

For east-west streets, the application of the sun access time windows would have a dramatically different effect on allowable building heights than on north-south streets. On north-south streets, time windows for sun access can be centered more or less at noontime depending on EST or DST, but on east-west streets, significantly lower building heights would result if a time window would start two hours or even one hour prior to noontime.

In order to design an equitable standard that would produce similar building heights on north-south and east-west streets, the three-hour time window allowing sunlight to east-west streets could only start at approximately noontime (12:18 p.m. DST, 11:18 a.m. EST) and would reach into the afternoon hours. At the key date of September 21st, the five-hour standard would start at one hour prior to noon and the seven-hour standard two hours prior to noon.

The third criterion for sun access standards would take into consideration a requirement for symmetry of street sections. Buildings facing each other on north-south streets should be of equal height. However, on east-west streets, sun access standards would not create a symmetrical street section. The standard could only define building heights on the south side of an east-west street (for the obvious reason that the sun does not shine from the north).

In the analysis sections of this report, field studies document measurement of the duration of sunlight to selected streets. The results of these field studies informed the final setting of time windows for sun access standards. They are explained in the recommendation section of the report.

Notes:

Arens, Edward. "Designing for an Acceptable Wind Environment". 1981. Transportation Engineering Journal, 107, 127-141..

Bassett, F. Zoning. New York: Russell Sage Foundation, 1940.

Davenport, A.G. "An Approach to Human Comfort Criteria for Environmental Wind Conditions," CIB/WMO Colloquia, Teaching the Teachers, Swedish National Building Reesearch Institute, Stockholm, Sweden, 1972.

Davis, Howard. "The Future of Ancient Lights." Journal of Architectural and Planning Research, 6:2, 1989.

J.C.R. Hunt, E. C. Poulton, and J. C. Mumford. "The Effects of Wind on People," Building and Environment. 11, 15-28, 1976. Pergamon Press.

P.S. Jackson. "The Evaluation of Wind Environments," Building and Environment. 13, 251-260, 1978, Pergamon Press.

Loyer, Francois. "Paris, Nineteenth Century Architecture and Urbanism." New York, 1988.

Midtown Development, Department of City Planning, New York City, 1982

E.A. Pearce and C.G. Smith. The Times Books World Weather Guide, Times Books, 1984.

Environment Canada, Atmospheric Environment Service, "Canadian Climate Normals/Normales Climatiques Au Canada", Volume 5, 1982.

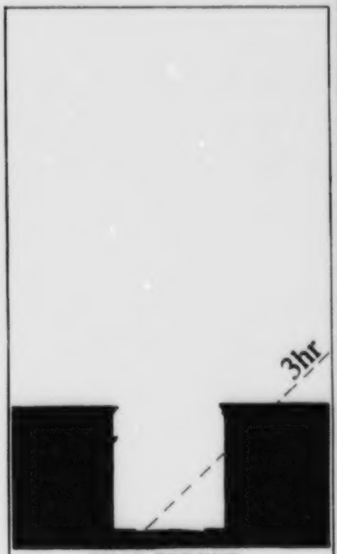
W.H. Melbourne. "Criteria for Environmental Wind Conditions," Journal of Industrial Aerodynamics, Vol 3, 241-249, 1978.

A.D. Penwarden. "Acceptable Wind Speeds in Towns," Building Science, Vol. 8, 259-267,1973.

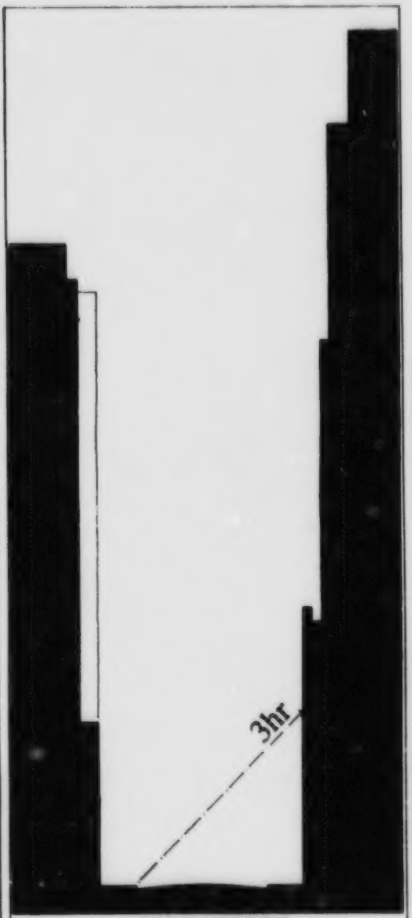
3. STUDY METHOD

The methodology section of this report explains the techniques used by members of the Toronto Study Team in measuring the amount of sunlight that falls on selected streets and open spaces in the Central City Area. The second part of this section describes laboratory experiments conducted with scale models built in Berkeley, by the Berkeley team. The experiments test alternative scenarios for three Toronto districts and include wind tunnel simulations, sun and shadow studies, and mathematical modeling of comfort conditions.

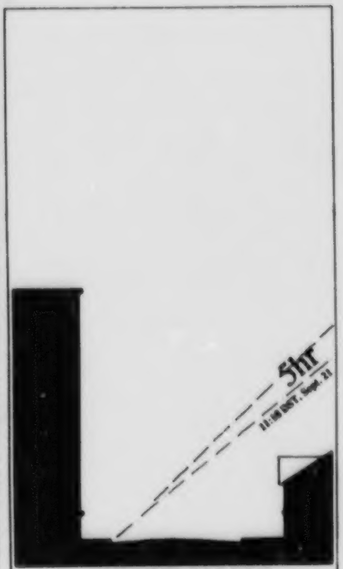
The section drawings on pages 25, 45, 46, 47, 55, and 151-156 have been drawn at the same scale and reduced to approximately 1cm = 7m (1: 700).



PEAR STREET
Near Duncan



Bank of Nova Scotia **KING STREET** Imperial Bank of Commerce



SHUTER STREET
Near Mutual

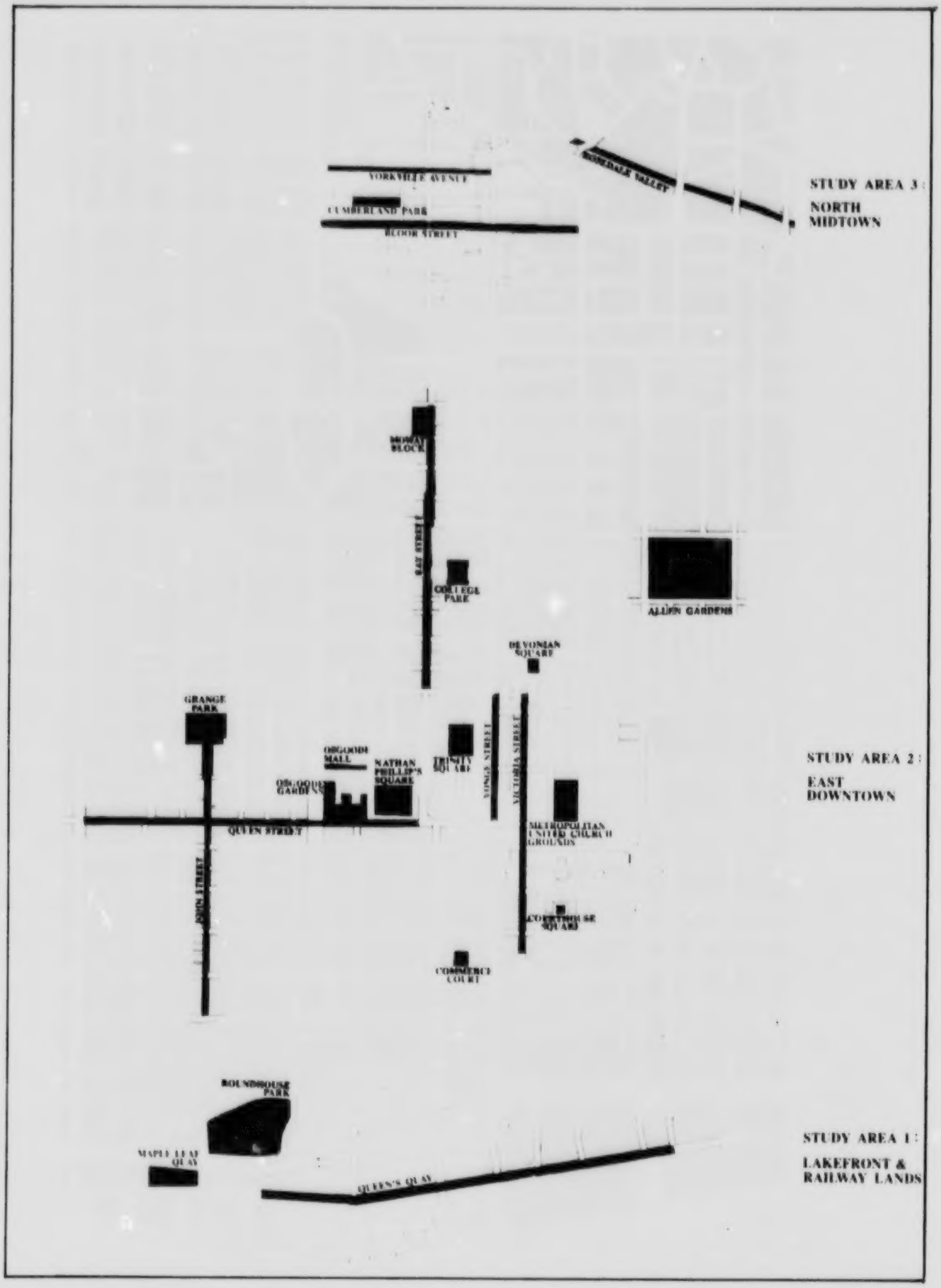

YORKVILLE AVENUE
CUMBERLAND PARK
BLOOR STREET
ROSEDALE VALLEY
STUDY AREA 3 :
NORTH MIDTOWN
BAY STREET
COLLEGE PARK
ALLEN GARDENS
DEVONIAN SQUARE
GRANGE PARK
OSGOODE MALL
OSGOODE GARDENS
NATHAN PHILLIP'S SQUARE
TRINITY SQUARE
YONGE STREET
VICTORIA STREET
STUDY AREA 2 :
EAST DOWNTOWN
QUEEN STREET
METROPOLITAN UNITED CHURCH GROUNDS
JOHN STREET
COURTHOUSE SQUARE
COMMERCE COURT
ROUNDHOUSE PARK
MAPLE LEAF QUAY
QUEEN'S QUAY
STUDY AREA 1 :
LAKEFRONT & RAILWAY LANDS

Fig. 3.1 Streets and Open Spaces Studied. The areas within the three circles were modeled for laboratory studies.

3.1 Field Studies Methodology

Methodology Used to Analyze Existing Sun Access and Open Spaces in the Central City Area

In collaboration with the Planning Department, the research team selected a number of representative streets and open spaces for an analysis of existing sunlight and shadow conditions. These streets and open spaces (shown in Fig. 3.1) were chosen because they were important locations in the city, have high potential for development on adjacent properties, and were noted for heavy pedestrian use.

Photographic techniques were used to study existing sunlight and shadow conditions. At selected streets, fish-eye lens photographs were taken at all intersections and midblock along both sidewalks, in order to quantify the duration of sunlight penetration to the sidewalk. The standardized location of the shots was at the crosspoint of lines drawn two meters from the lot line at a height of 1.0 meter above the sidewalk level.

Slides of the intersections and midblocks were superimposed over a diagram displaying the sun's path across the sky on the photograph. Looking at the composite picture, it was possible to identify the times of the day when sunlight is available at each location. An example of such a photograph is shown in Fig. 3.2.

The sunlight duration was mapped on street maps, in bars representing one-hour duration on the sidewalks (as an example see Fig. 3.3). All results were then gathered and mapped together on an abstracted city map (Fig. 3.4).

On streets in those areas selected for laboratory modeling, the data was taken

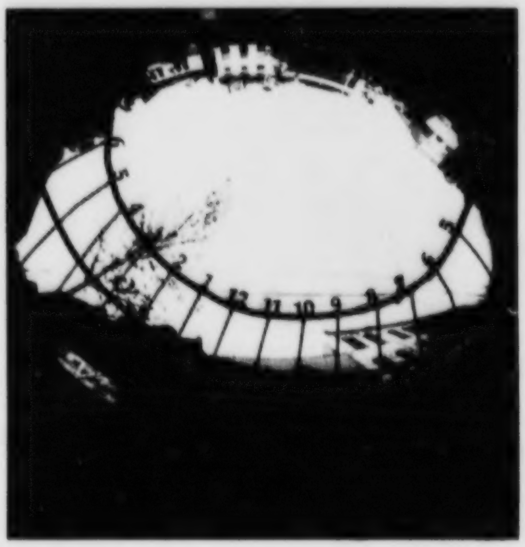
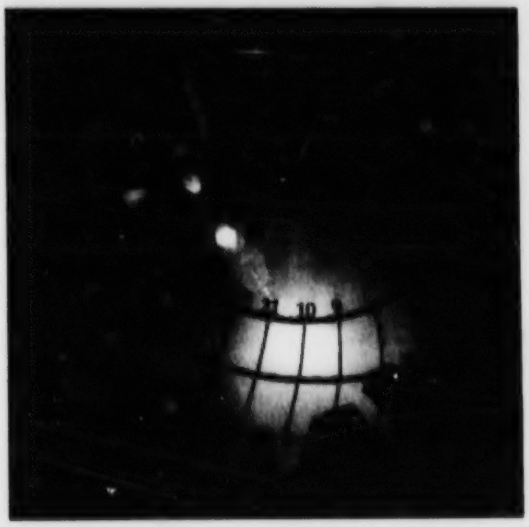


Fig. 3.2 Fisheye Pictures:

a) Queen Street, midblock between Soho and Spadina, taken on the southside of the street.



b) City Hall, Nathan Phillips Square, taken at the center of the Square.

The superimposed lines indicate the path of the sun at the summer solstice (June 21), the equinox (March/September 21), and the winter solstice (Dec. 21). The superimposed lines are used to measure the duration of available sunlight.

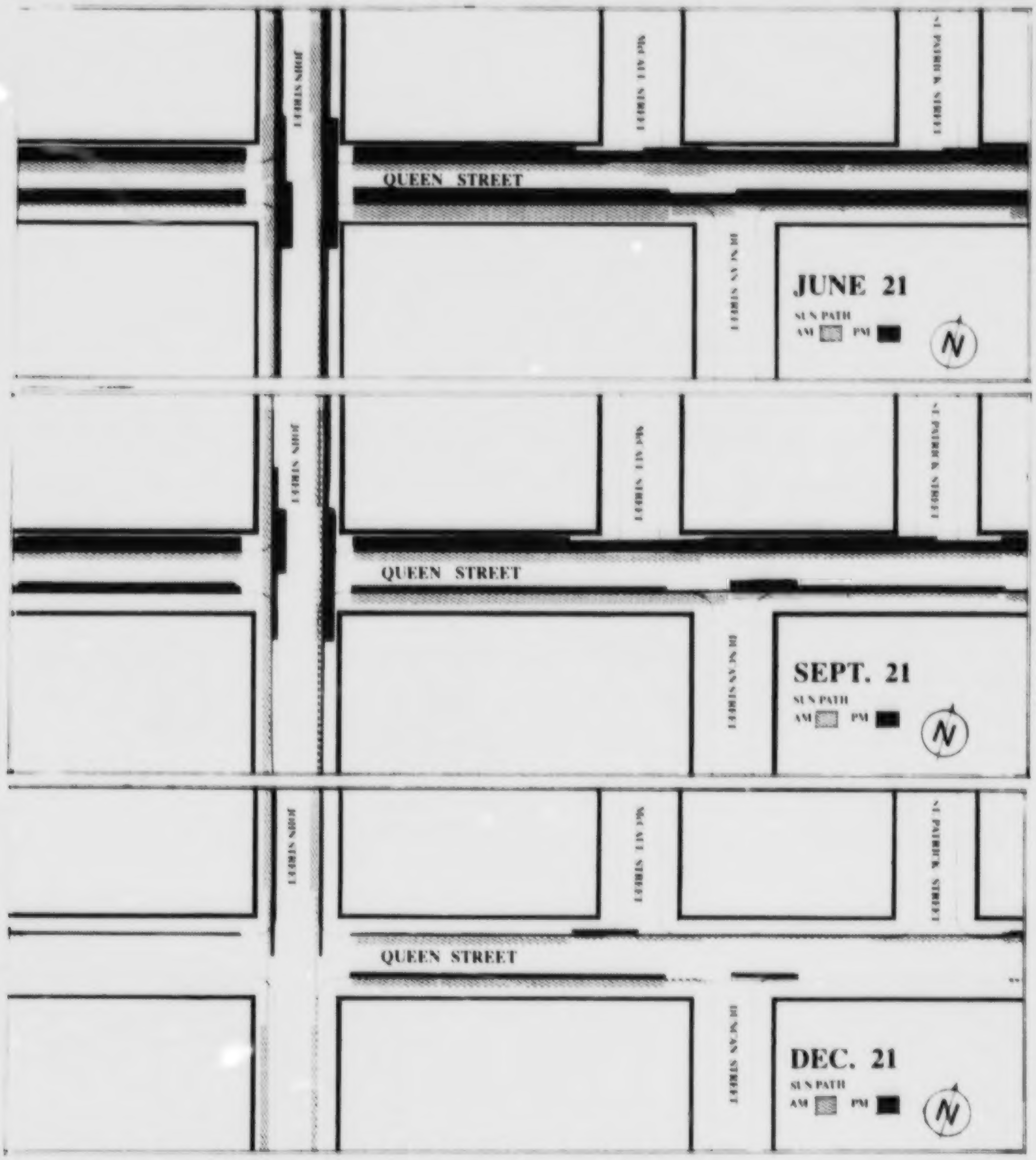

JOHN STREET
McCAUL STREET
ST. PATRICK STREET
QUEEN STREET
DUNCAN STREET
JUNE 21
SUN PATH
AM ▨ PM ■
N
JOHN STREET
McCAUL STREET
ST. PATRICK STREET
QUEEN STREET
DUNCAN STREET
SEPT. 21
SUN PATH
AM ▨ PM ■
N
JOHN STREET
McCAUL STREET
ST. PATRICK STREET
QUEEN STREET
DUNCAN STREET
DEC. 21
SUN PATH
AM ▨ PM ■
N

Fig. 3.3 Abstracted maps of Queen Street showing the duration of sunlight on September 21, June 21, and December 21.

from readings taken on the models, under a parallel-beam light source using hourly readings of sun and shadow distribution. Model readings include approved buildings that are not yet built.

The methodology used for evaluating open spaces followed a similar pattern: field readings were done by laying a grid over the park or open space and then taking fish-eye photographs. The results were then mapped. Model readings were taken for open spaces within the three study areas designated for laboratory modeling. The different model sites include approved buildings, not yet built.

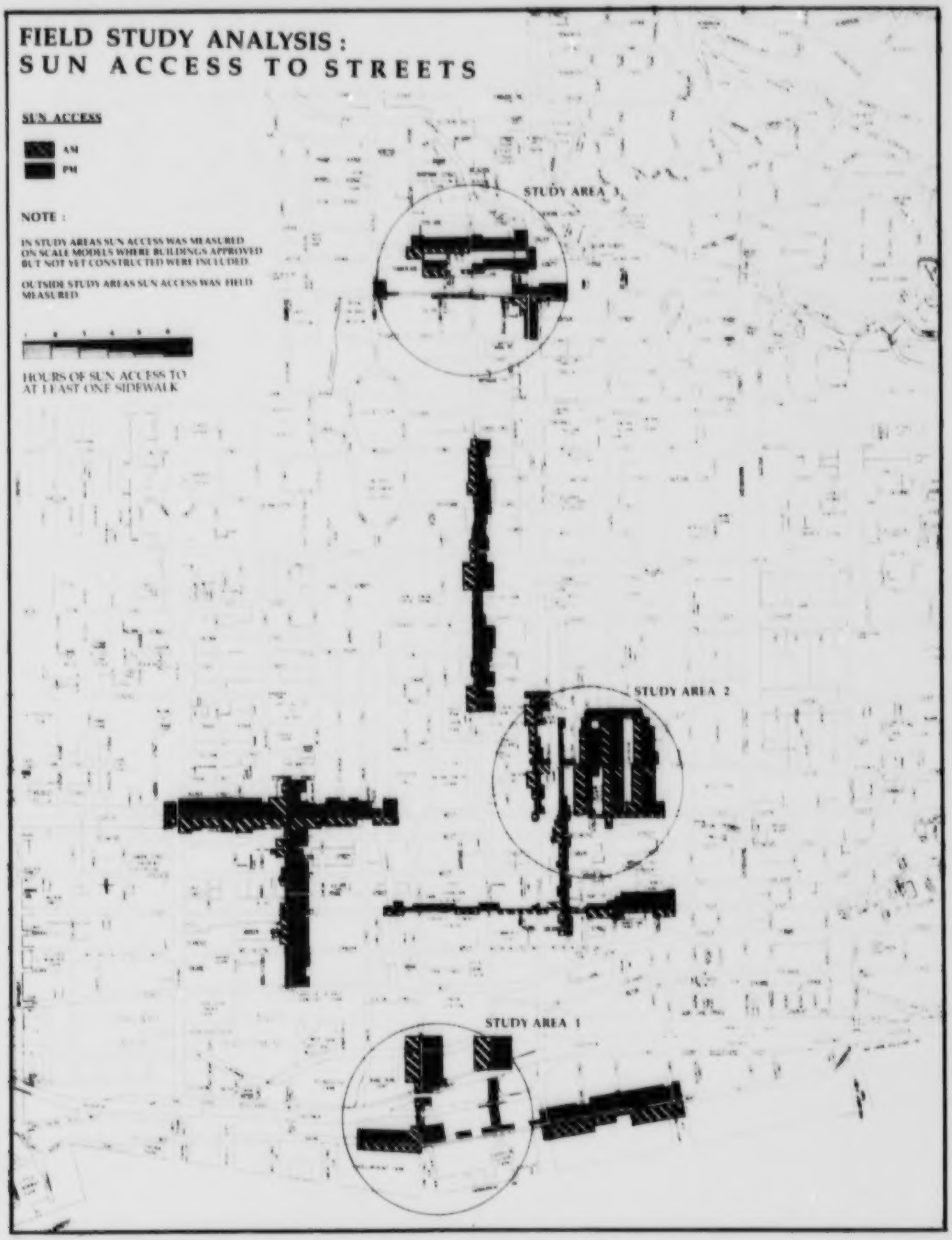

FIELD STUDY ANALYSIS :
SUN ACCESS TO STREETS
SUN ACCESS
AM
PM
NOTE :
IN STUDY AREAS SUN ACCESS WAS MEASURED ON SCALE MODELS WHERE BUILDINGS APPROVED BUT NOT YET CONSTRUCTED WERE INCLUDED
OUTSIDE STUDY AREAS SUN ACCESS WAS FIELD MEASURED
1 2 3 4 5 6
HOURS OF SUN ACCESS TO AT LEAST ONE SIDEWALK
STUDY AREA 3
STUDY AREA 2
STUDY AREA 1

Fig. 3.4 Summary of the Field Study Analysis of Sun Access to Streets.

3.2 Laboratory Studies Methodology

Selection of Study Areas

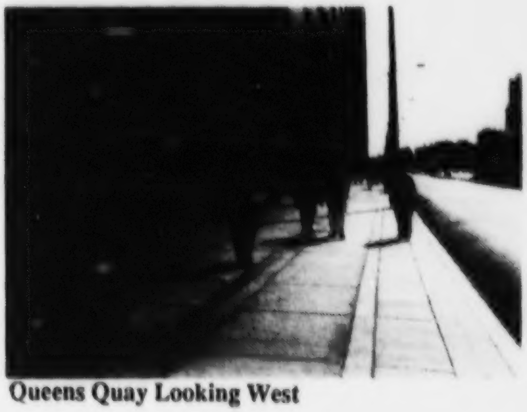
Lakefront and Railway Lands *(Site 1)*

Bounded by Simcoe and Yonge, Union Station, and the Waterfront, this area was selected because it is a part of the city that is targeted for major development. The present zoning allows for high density development similar to the downtown financial district.

Streets within the study area are important pedestrian streets, with regional significance. They are major pedestrian links from the city to the waterfront and from the skydome to Union Station, which will become more heavily used in the future. York Street and Bay Street, in particular, will carry large numbers of tourists and visitors to the lakefront and to the ferry terminal. Similarly, in the future, the new Esplanade will become one of the frequently traveled promenades in the City. Like University Avenue, it will create an impression of Toronto's streets in the minds of the City's visitors.

Queens Quay, York Street Slip

Lakefront Promenade


Queens Quay Looking West

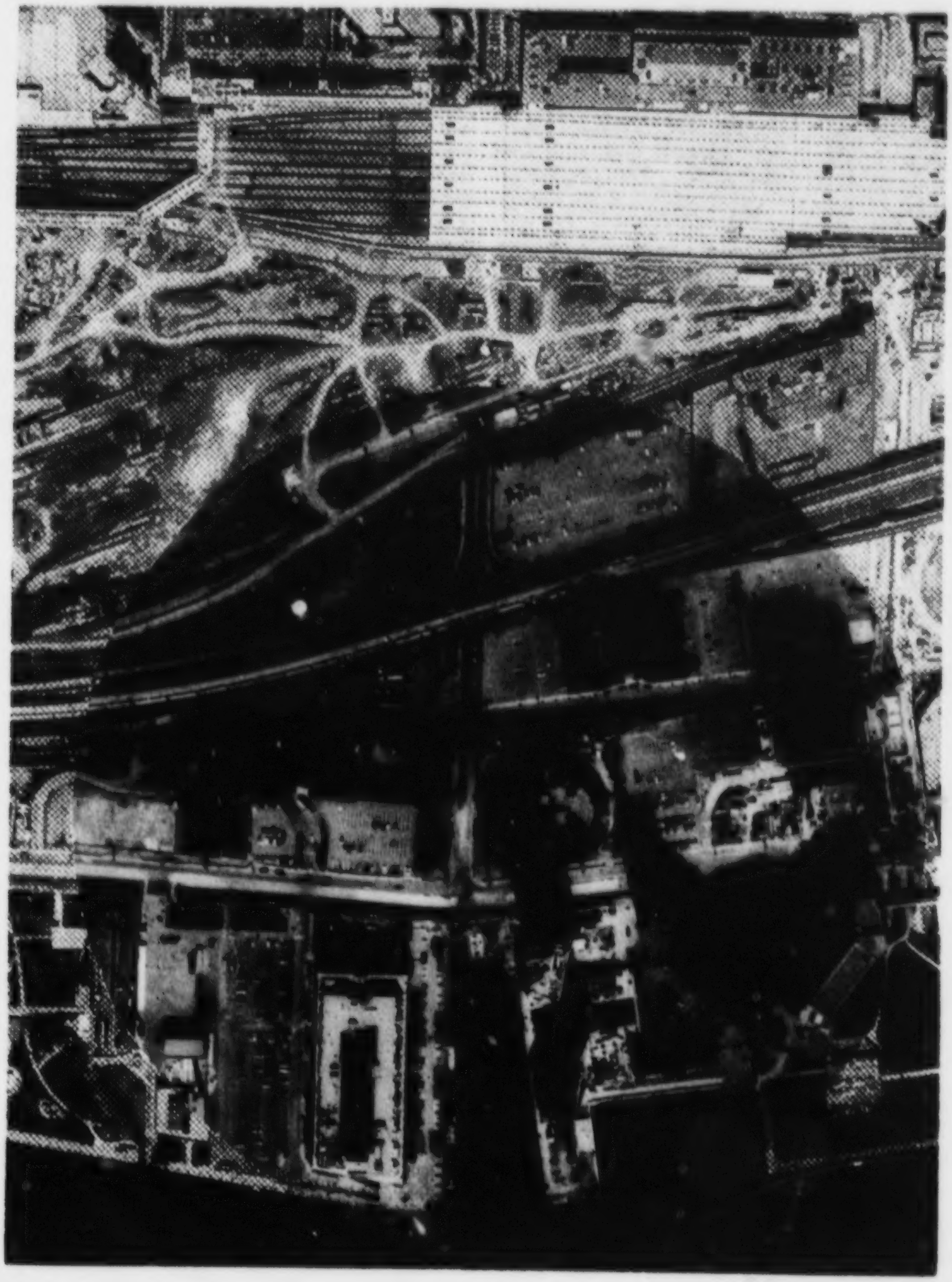


Fig. 3.5 Aerial View of the LakeFront.

East Downtown *(Site 2)*

The East Downtown area was selected as being representative of a medium-density, mixed-use (commercial and residential) district. The area is characterized by large tracts of undeveloped or underdeveloped land. In this area a number of development applications involving a significant amount of residential development have been filed with the Department of Planning and Development.

Dundas Street, in the north, and Queen Street, to the south, are main streets. They both have streetcar lines and are used as shopping and access streets by many pedestrians.

Mutual Street and several other north-south streets will be developed as residential streets centered on Shuter Street. Presently, they are empty and lined with parking lots. Shuter Street does not carry heavy vehicular traffic and could be valuable as an east-west connector for pedestrians and bicyclists from the residential district to the center of the city. Bond Street is a special street, as it is lined with a number of renowned historically significant public buildings such as St. Michael's Choir Separate School and the Metropolitan United Church buildings.

East Downtown seen from Mutual Street.

Mutual Street looking north, near Shuter.

Metropolitan United Church.

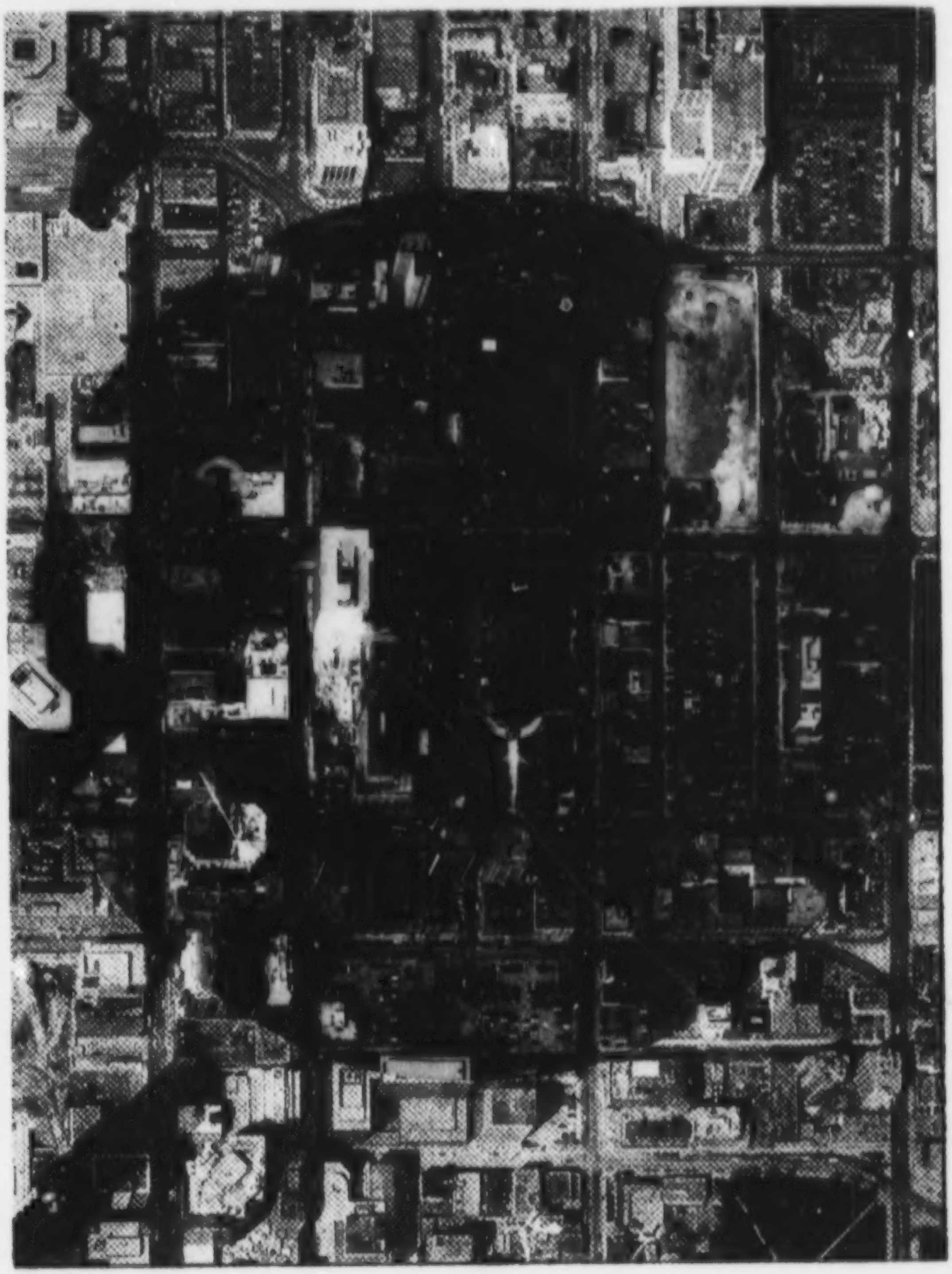


Fig. 3.6 East Downtown, Aerial View.

The Bloor Street Midtown Area

(Site 3)

The third area studied by the team is centered on Bay and Bloor Streets. The area was selected because it encompasses districts with two quite distinct characters, linked closely together: the Bloor Street Midtown shopping district with high-density commercial development, and, to the north, the Yorkville district with low-density commercial development including boutiques, restaurants, and fashionable stores. The northern border of the Yorkville district is adjacent to an exclusive residential area. This residential area runs along Hazelton Avenue and has two-and-a-half-story Victorian houses shadowed by tall trees. The Midtown Area is an example of an area that makes a transition from the dense highrise commercial environment of Bloor and Bay Streets to a low-rise residential area north of Yorkville Avenue.

The study area is bounded by Avenue Road to the west and Church Street to the east and stretches north-south from Yorkville to Charles. Bloor and Bay Streets have experienced major developments during the past fifteen years, causing strong winds at street corners (one of the most notorious corners in the city is the intersection of Bloor and Yonge) and sun-deprived sidewalks. On the other hand, both streets are major shopping streets, and Bloor Street has recently been the site of major landscaping initiatives.

Bloor Street looking north on Bay Street.

Cumberland Street.

Yorkville Avenue.

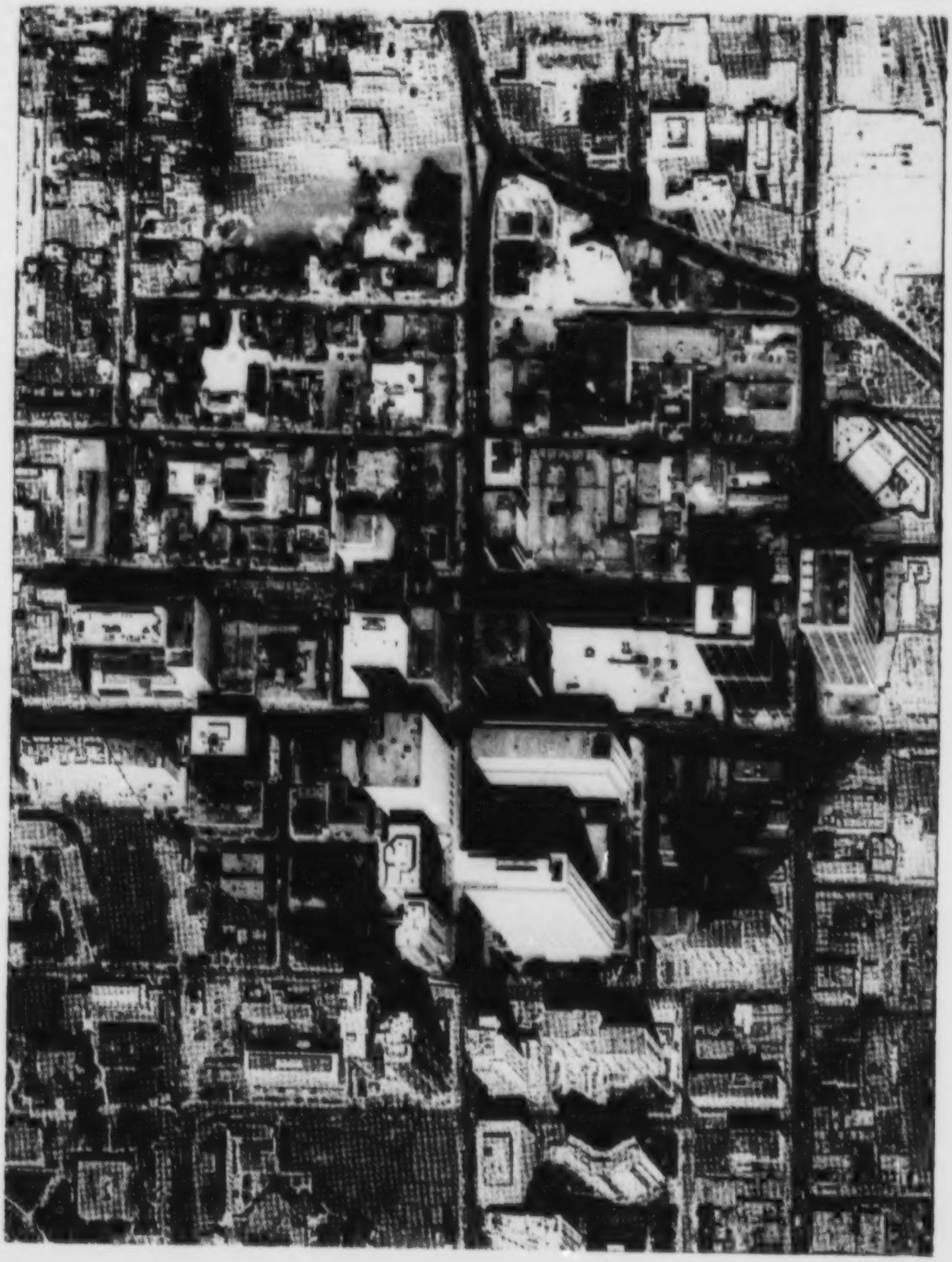


Fig. 3.7 Bloor Street, Midtown Area, Aerial View.

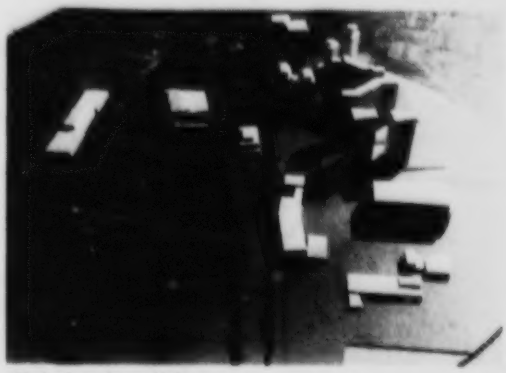
3.2.1 Modeling of Development Scenarios on Selected Sites

The Berkeley study team constructed scale models of each of the three selected areas for use in wind tunnel simulation and for shadow analysis. The models depicted existing buildings, streets, and open spaces, including those developments under, or approved for construction as of June 15, 1990. For the production of scale models, 1:2000-scale property maps and building footprint maps from the City of Toronto's computer database were used to measure the horizontal dimensions of buildings and blocks. Aerial photographs and a mylar overlay with spot elevations measured photogrammetrically were used for measuring vertical dimensions and building massing. The scale selected for the modeling measured 1:360 (1" = 30') for the North Midtown and the East Downtown sites. The LakeFront site was built at a smaller scale of 1:480 (1" = 40') because the large size of the buildings allowable under current planning laws would have impaired the accuracy of the wind tunnel simulations had they been modeled at the larger scale of the other two sites.

Potential Development

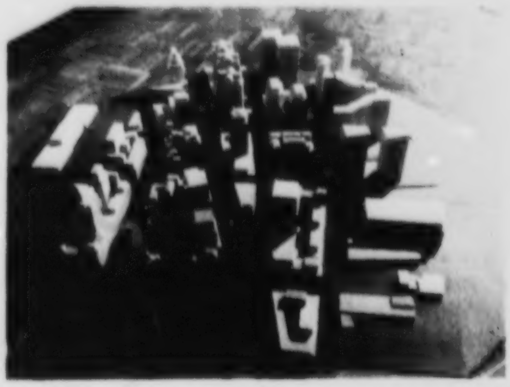
Together with the staff of the Department of Planning and Development, the study team identified sites where future development was currently under consideration or possible under existing planning controls. For these sites, the planning staff obtained preliminary design drawings from project sponsors, or, in the absence of any design drawing, the Berkeley team together with the Planning staff determined possible building volumes. The modeling of this potential future development considered the maxi-

Lakefront and Railway Lands



Existing Conditions.

Buildout under Potential Development.



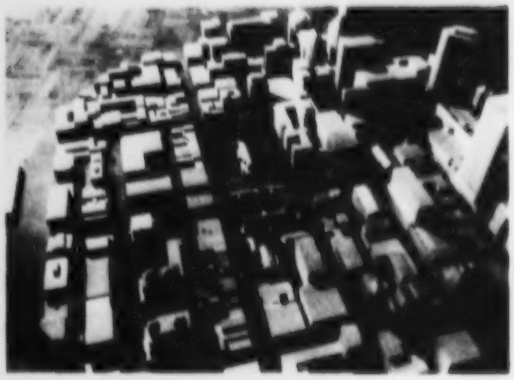
Buildout under Mitigated Development.

East Downtown Area

North Midtown Area

Existing Conditions.

Existing Conditions.



Buildout under Potential Development.

Buildout under Potential Development.

Buildout under Mitigated Development.

Buildout under Mitigated Development.

mum allowable coverage and/or units per hectare as well as existing height limits, setback constraints, and guidelines regarding light, privacy, and views.

In considering potential development opportunities on sites that could be assembled for mixed-use projects, the intent was to generate a hypothetical development scenario based on the existing planning policies and zoning regulations. In particular, it was assumed that the modeled hypothetical project should not exceed the maximum density permitted in the Official Plan and the maximum height limit established in the Zoning By-Law.

In examining the existing policies and regulations that would apply to these potential sites, it was also apparent that, with a small number of the selected sites, modifications to the height and density controls would be required in order to model a more feasible and realistic project that did not compromise standardized building techniques. These changes were made in those areas where the Planning and Development Department has acknowledged that the existing density and/or height controls could be modified to accommodate appropriate comprehensive development.

Mitigated Development

After analyzing the existing conditions and the potential future development through wind tunnel and shadow simulations, the second future scenario development was modeled, based upon modified planning controls.

The modeling and testing of the mitigated scenario was guided by the following objective: demonstrate that it is possible to mitigate the effect built form has on the microclimate of streets by modifying the placement, height, and massing of future development.

For this purpose we constructed building envelopes that follow mitigation measures. These measures include sun access criteria and considerations in the placing of buildings that were intended to reduce strong surface winds.

Three assumptions were made in the modeling of this mitigated scenario: One, we decided to compare equal amounts of future development potential. For example, a set of buildings on a given site modeled at a density of 6 times coverage under the potential scenario was modeled on the identical site with the same coverage under the mitigated scenario. This assumption is important, because, had we simply lowered the coverage under the mitigated scenario, an improvement in the climatic conditions could be attributed to the lower coverage and not to the mitigation measures.

Prior to conducting the experiment, it was anticipated that at some level, mitigation measures would constrain the density of future development. The modeling experiment revealed that mitigation measures could be successfully applied up to a maximum density of 10 times coverage. The effect of comfort controls on density is explained in detail in section five.

The second assumption was made with regard to the existing zoning heights. Under the mitigated scenario, we modified the height limits according to the sun access standard, but operated under the assumption that the zoning height limits would remain intact above those portions of properties that are unaffected by the sun access standards. The reason for this assumption is identical to the reason given in assumption one.

Thirdly, we assumed that a "build-to" line would be introduced. Such a "build-to" line would require buildings to be built along the perimeter of city blocks, at the property line, or at a line that runs parallel to the property line. If buildings follow such a line, a continuous street wall will result. A street wall provides shelter from the wind and therefore contributes to a better microclimate at street level.

These three assumptions have guided us in the modeling. It was the intent of this experiment to model building envelopes representative of the kind of development that might be accommodated in Toronto in the future. Therefore, development sites include various building lot dimensions in a range of different Official Plan districts. The model sites were located on narrow and wide streets, in the east-west and north-south direction. Each street was assigned a sun access standard of either three or five hours of sunlight encompassing the midday period. For reasons of acquiring a representative sample, care was taken in the assignment of these time windows with the intent that enough streets of different width and orientation were tested under the three- or the five-hour time window.

Specifically, the North Midtown Area, Bloor Street, Bay Street, and Yonge Street were assigned a three-hour window of direct sunlight. Scollard Street, Cumberland Street, and Yorkville Street were selected for five-hour streets. In the East Downtown area, Dundas, Queen, Victoria, Church, Dalhousie, and Jarvis Streets were modeled as three-hour streets. Shuter, Yonge, Bond, and

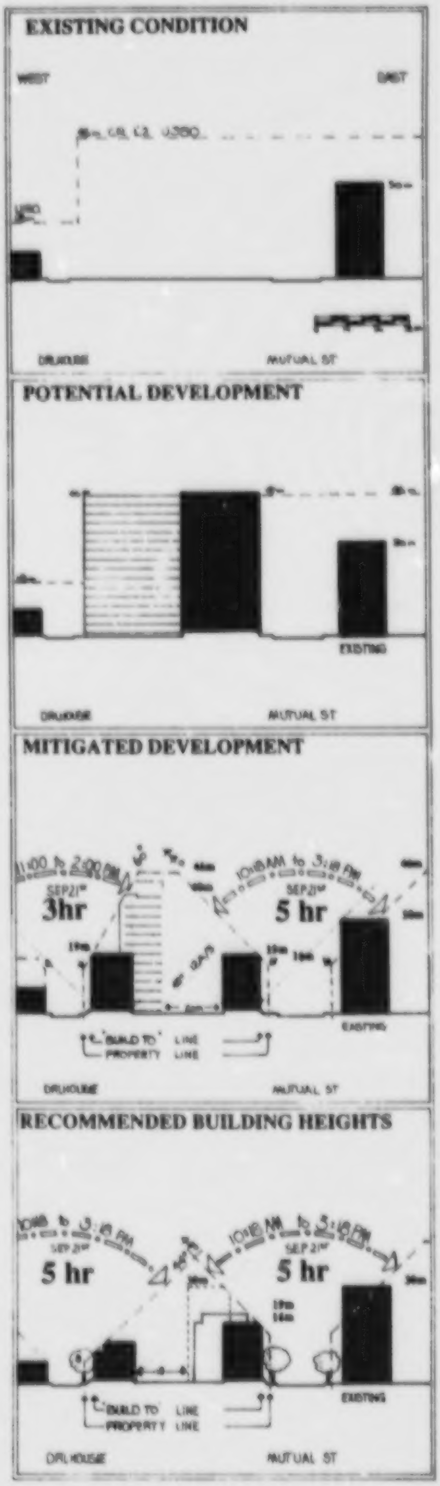

EXISTING CONDITION
WEST
EAST
DRUHOUSE
MUTUAL ST
POTENTIAL DEVELOPMENT
EXISTING
DRUHOUSE
MUTUAL ST
MITIGATED DEVELOPMENT
11:00 to 2:00 PM
SEP21st
3hr
10:18 AM to 3:18 PM
SEP21st
5 hr
"BUILD TO" LINE
PROPERTY LINE
EXISTING
DRUHOUSE
MUTUAL ST
RECOMMENDED BUILDING HEIGHTS
10:18 to 3:18 PM
SEP 21st
5 hr
10:18 AM to 3:18 PM
SEP 21st
5 hr
"BUILD TO" LINE
PROPERTY LINE
EXISTING
DRUHOUSE
MUTUAL ST

Fig. 3.8a Modeling Methodology

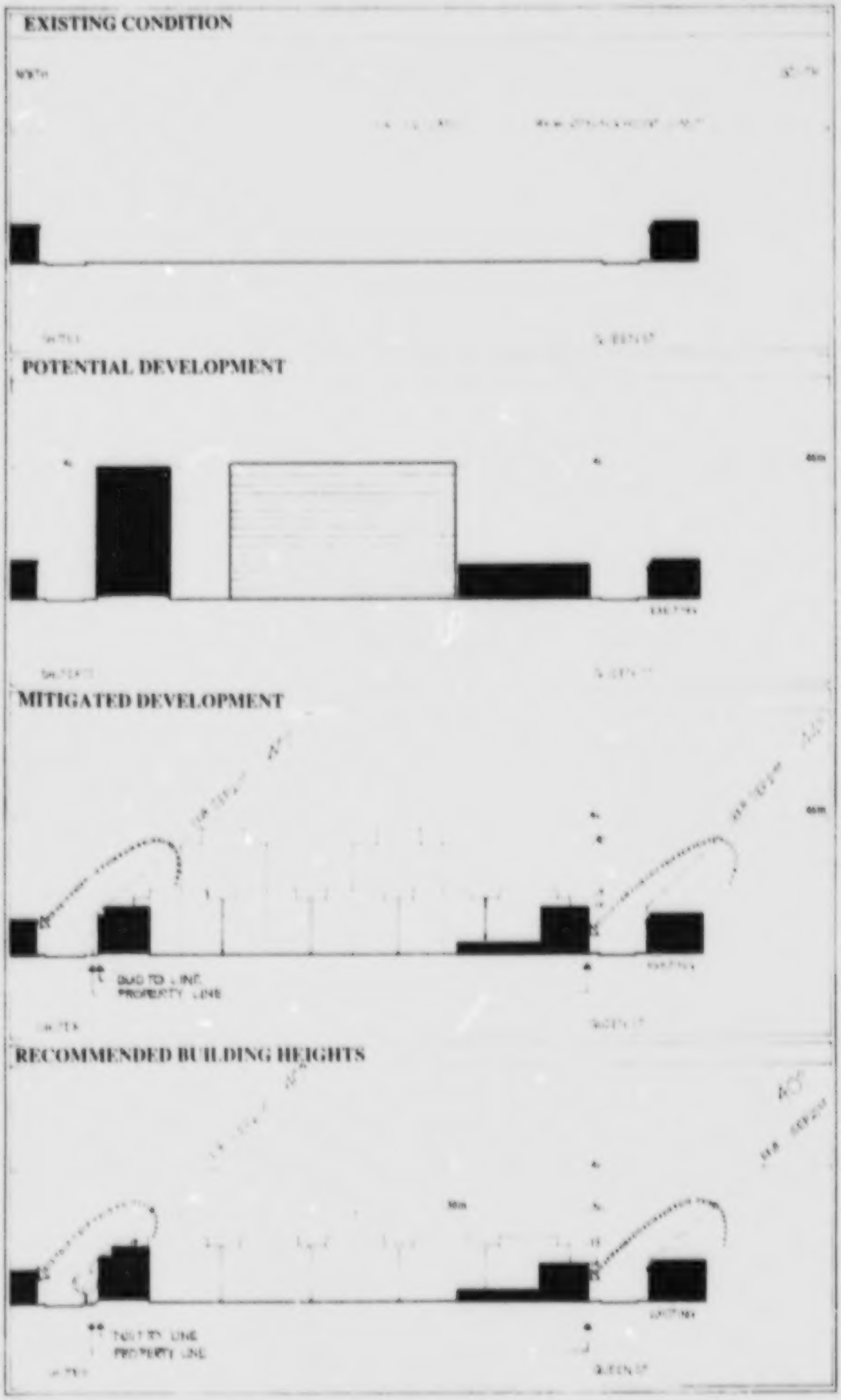

EXISTING CONDITION
POTENTIAL DEVELOPMENT
MITIGATED DEVELOPMENT
BUILD TO LINE
PROPERTY LINE
RECOMMENDED BUILDING HEIGHTS
BUILT TO LINE
PROPERTY LINE
QUEEN ST

Fig. 3.8b Modeling Methodology

Mutual Streets were modeled as five-hour streets. In the Lakefront and Railway Lands area, the Esplanade, Harbour Walk, Queens Quay, Simcoe, York, Bay, and Yonge Streets were treated as three-hour streets.

The section views in Fig. 3.8a,b show one of our model sites in East Downtown. The drawings compare the potential building volumes and the mitigated scenario with additional mitigation measures that were established after the review of the test results. They were incorporated in the recommendations. These additional measures included, for example, the assignment of five-hour time windows for all predominantly residential streets in the study areas. The rationale for these assignments is explained in a street classification system in the recommendation section of this report.

In this mitigated development scenario, potential development sites were modeled to represent realistic building proposals. They are not only volumetrically possible within the Official Plan requirements and the sun access planes, but are based on assumptions about building and site design and development worked out with the Planning and Development Department. Depending on the site, a combination of residential and commercial floorplates and building configurations was modeled in a manner which satisfied the goals and constraints of the Official Plan.

Selecting locations for Measurements

Within the models, points along some of the streets and in the parks were selected for measurements of sun and wind conditions. These points were strategically chosen to capture the range of conditions and effects in each area. Particular care was taken to place test points in locations which would be heavily used by pedestrians. Points were also placed in areas where it was hypothesized that major new buildings would create substantial shadow and wind impacts at street level.

3.2.2 Methodology for Sunlight Analysis

To measure the shading effects of each of the building configurations, sun conditions were simulated for every daylight hour between the hours of 8 a.m. and 7 p.m.. A parallel-beam light source was positioned near the model and moved to simulate the path of the sun throughout the day. Stations were marked to reflect the sun's altitude and azimuth (bearing angle) at each of the dates and times for which solar data was required.

The solstices and equinoxes were selected to represent solar conditions for an entire season, where March 21 represented the spring sun condition; June 21 represented the summer sun; September 21 represented the fall sun; and December 21 represented the winter sun.

3.2.3 Wind Tunnel Testing

Wind tunnel studies were performed to examine the pedestrian-level wind velocities and directions around the three study sites. To understand how development would influence wind conditions at the sites, pedestrian-level wind speeds and turbulence levels were measured at selected points under existing, potential, and modified planning controls. Smoke visualization was used to study the characteristic air flow patterns in the streets and to document local wind directions.

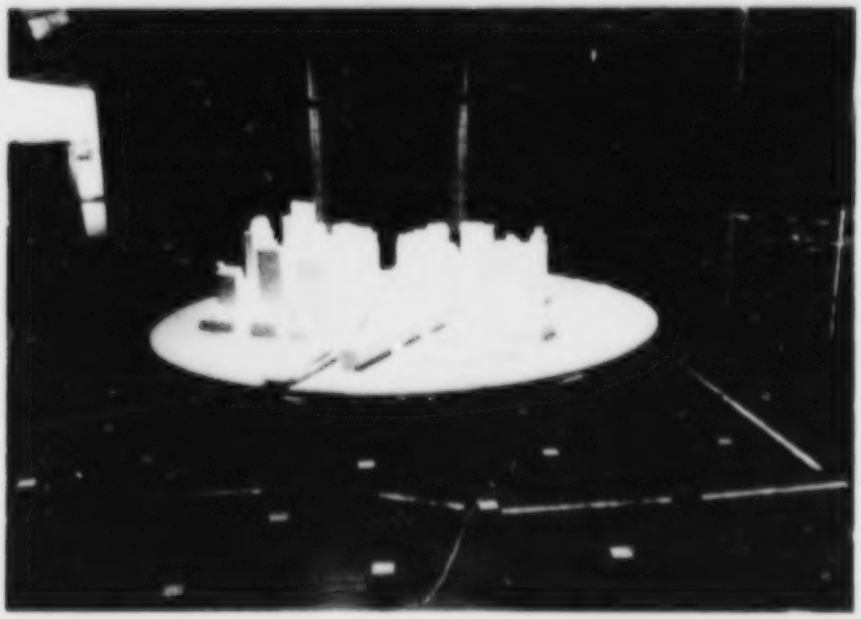


Fig. 3.9 Wind Tunnel Study

The results of the wind tunnel simulation are shown on maps included in the analysis section of this report. A detailed discussion of the methodology used in the windtunnel simulation can be found in Appendix I.

3.2.4 Thermal Comfort Modeling

Combining the results of the wind tunnel simulations with the results from the sun and shadow studies formed the basis of the thermal comfort analysis. This analysis is done with a mathematical model of thermal comfort conditions for pedestrians. Two personal and four climatological variables affect thermal comfort. They are a person's metabolic rate and clothing level, and the air temperature, air velocity, mean radiant temperature, and relative humidity. The second section of Appendix 1 details the assumptions made and the data used for the mathematical modeling. The results of the comfort prediction are shown on seasonal maps for existing, potential, and mitigated development scenarios in the analysis section of the report.

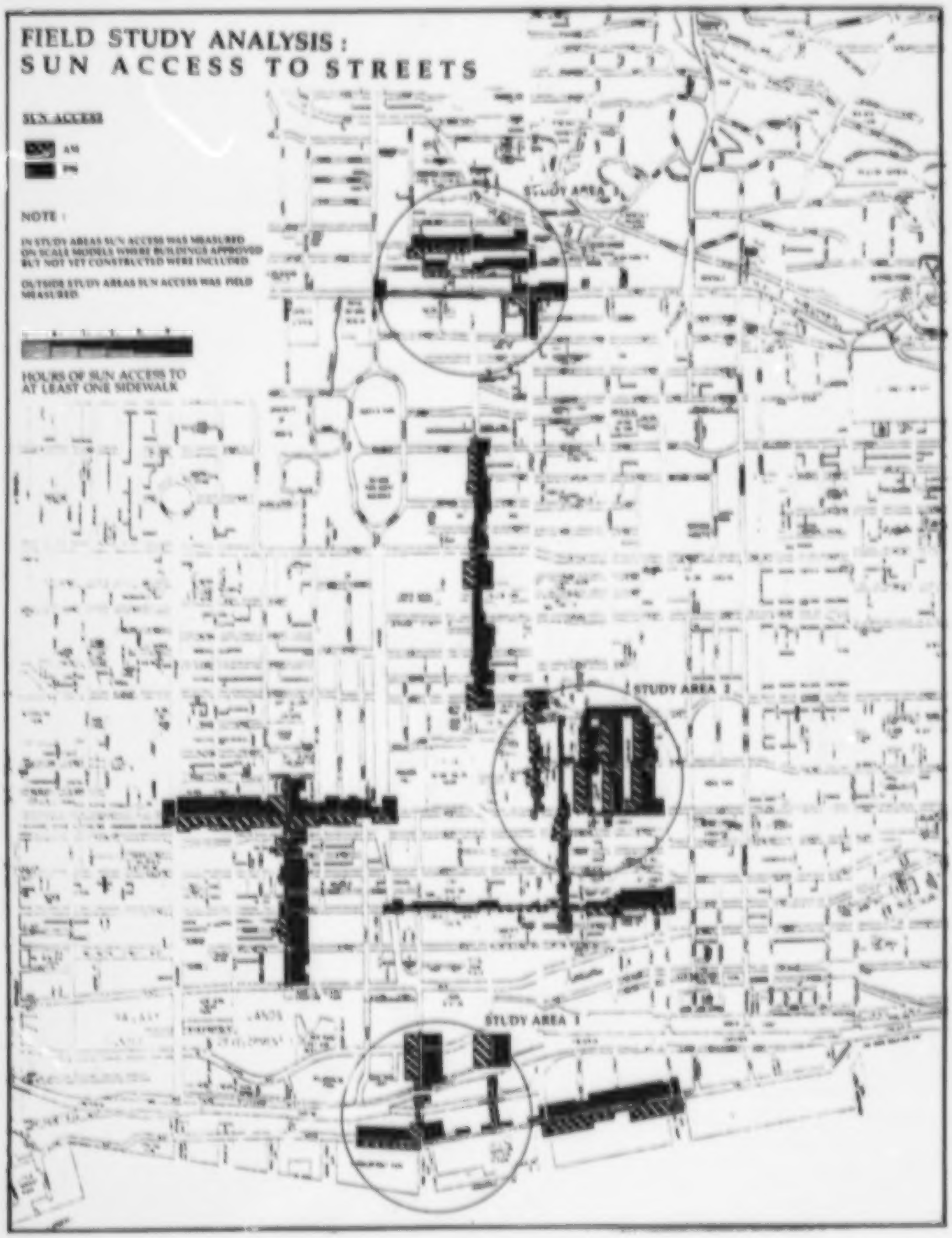

FIELD STUDY ANALYSIS :
SUN ACCESS TO STREETS
SUN ACCESS
AM
PM
NOTE :
IN STUDY AREAS SUN ACCESS WAS MEASURED ON SCALE MODELS WHERE BUILDINGS APPROVED BUT NOT YET CONSTRUCTED WERE INCLUDED
OUTSIDE STUDY AREAS SUN ACCESS WAS FIELD MEASURED
HOURS OF SUN ACCESS TO AT LEAST ONE SIDEWALK
STUDY AREA 3
STUDY AREA 2
STUDY AREA 1

Fig. 4.1 Field Study Analysis: Sun Access to Selected Streets in the Central Area.

4. ANALYSIS

This section of the report explains the results of the field studies and the laboratory simulation.

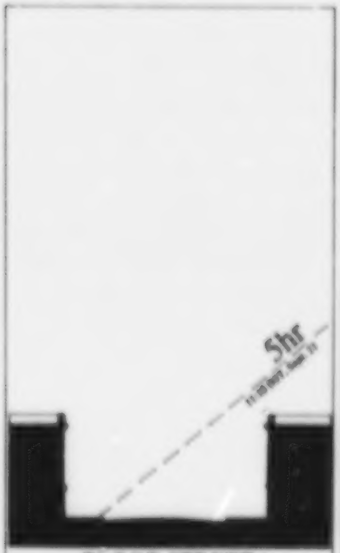
4.1 Field Study Analysis

4.1.1 Field Studies - Sunlight on Streets

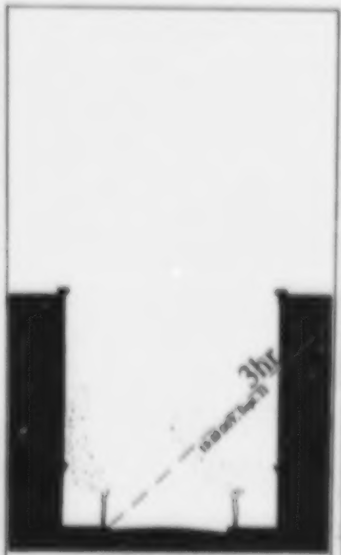
In order to analyze sunlight available to city streets, a photographic survey of selected streets was undertaken using a fish-eye lens. Selected streets were chosen as typical streets of the Toronto Central Area, and results of the photo survey are mapped on Fig. 4.1. The map shows solar access at the time of the fall equinox, September 21, which was identified as a critical time period for determining setting sun-access standards. The fall equinox is important because the sun's radiation at this time of year is a dominant factor in determining thermal comfort for pedestrians.

In reading Fig. 4.1, it is important to note that the map is an abstraction. Although the results are shown as bars aligning the entire length of the street, the points surveyed are only taken at the four corners of the intersections and once on each side of the street in the middle of the block. Thus, high buildings on a given block may shadow the sidewalk but may not be recorded on the map. More detailed information showing sunlight duration with greater precision are shown as an example on Fig. 3.3 in the previous section of the report.

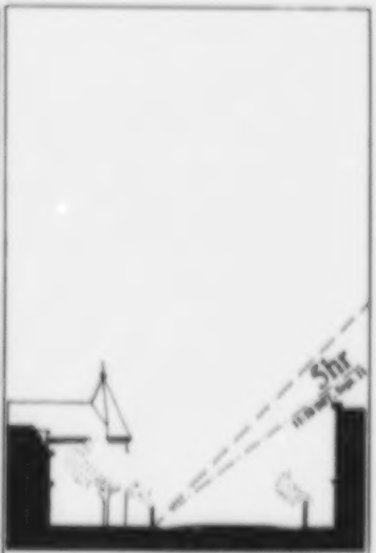
It is apparent from the survey that despite the high build-up of the city, many streets receive sunlight during most of the daylight hours at most times of the year. It is also evident, however, that some streets receive little sunlight due to the height built-up along portions of major east-west streets in the Central Area, such as Bloor Street, King Street, and Front Street.



BLOOR STREET
100 block



KING STREET
Near Spadina



QUEEN STREET
Near Peter

North-South Streets

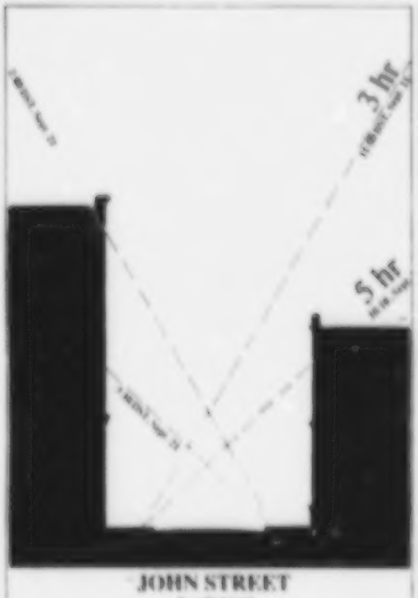
The rotation of the street grid of Toronto by 16 to 18 degrees to the west of north favours sunlight to north-south streets from late morning until early afternoon. For this reason, it is easier to provide sunshine on north-south street sidewalks during the lunch time than on east-west streets. A typical north-south street such as Bay Street between Dundas and Wellesley receives one to two hours of sunlight in the morning and two to four hours in the afternoon in many places. John Street between Front and Queen, which is lined by buildings of lower height, typically has one to two hours of sun in the morning and five to six hours in the afternoon. The most restrictive case that was studied, Victoria Street between Wellington and Dundas, receives an average of one to two hours of sun access daily.

The survey of north-south streets shows that streets in the Central Area receive anywhere from two hours to eight hours sun access per day. On average, streets in the Central Area receive five hours of sun access per day. The building heights that make five hours of sun access possible measure at an average 0.8 times the width of the street. For example, on a 26m street like Bay Street five hours of sun access would result in a street wall height at the property of 20m, or six to seven stories high, depending on commercial or residential floor heights.

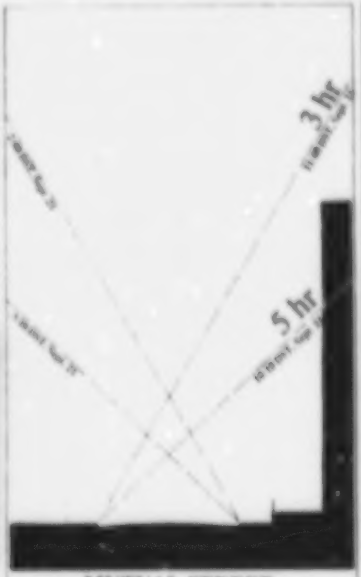
On a narrower street lined by higher buildings like Victoria Street, an average of three hours of sun access results when the relationship of street width to street wall height is approximately one to one-point-three-five (1:1.35). Here, a 20m wide street would have buildings of 27m height at the property line, or eight to ten stories.

East-West Streets

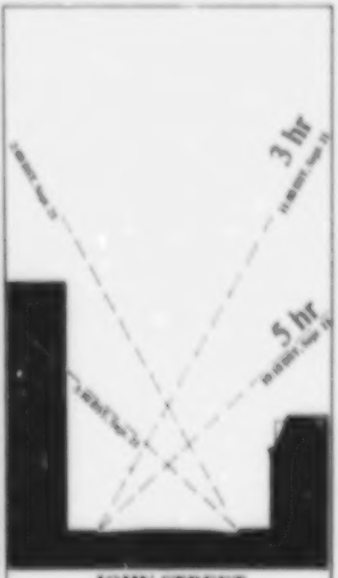
The north side of east-west streets receives sunlight during much of the day in September, while the southern side re-



JOHN STREET
Near Richmond

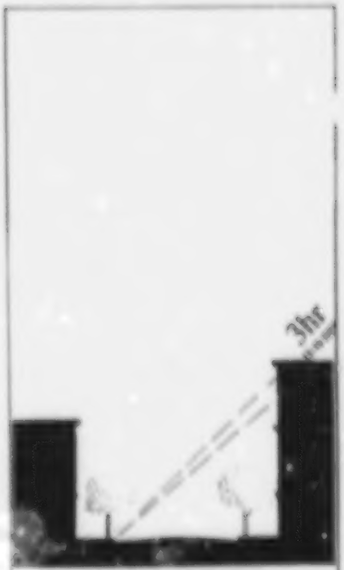


MUTUAL STREET
Near Queen



JOHN STREET
Near King

The section drawings on pages 25, 45, 46, 47, 55, and 151-156 have been drawn at the same scale and reduced to approximately 1cm = 7m (1: 700).



QUEEN STREET

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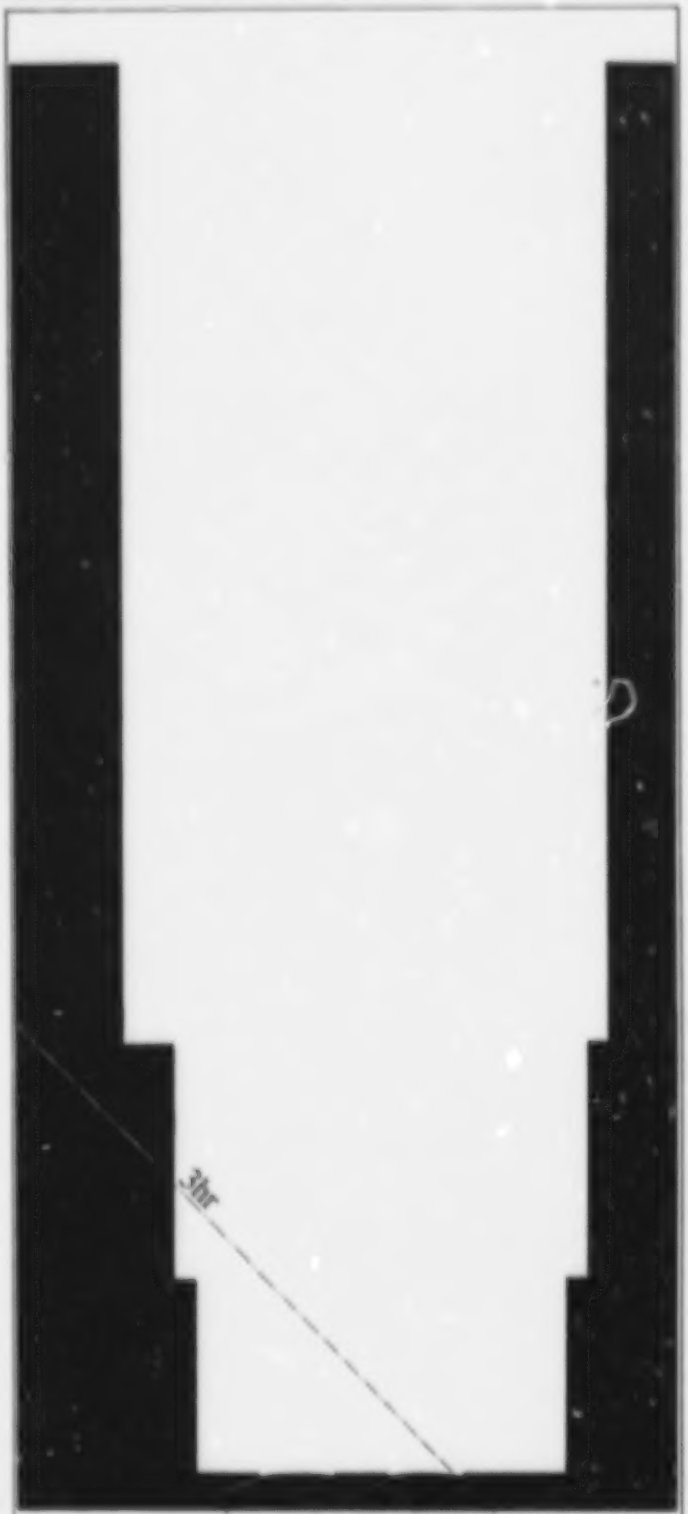


THE ESPLANADE

[illegible]

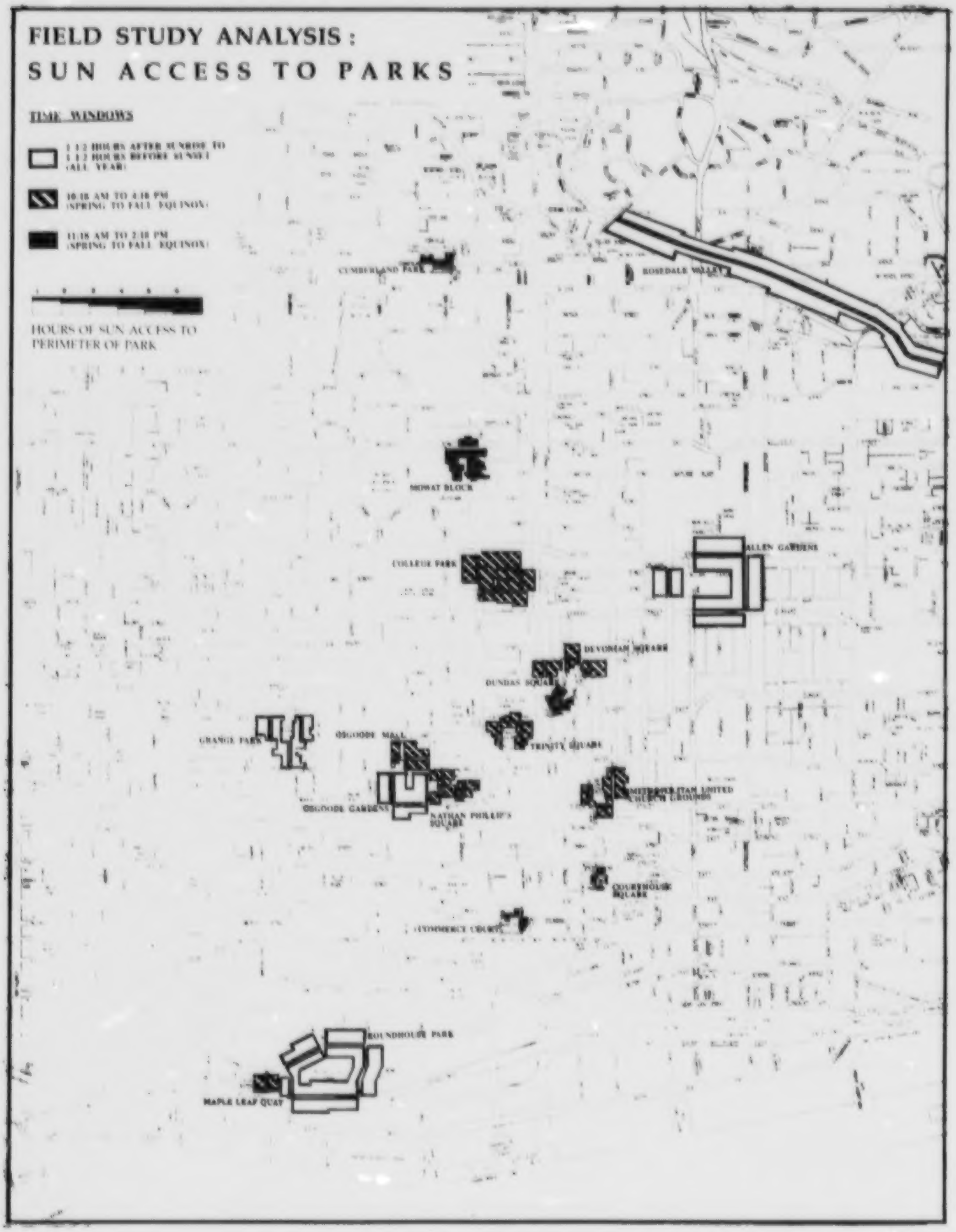

FIELD STUDY ANALYSIS :
SUN ACCESS TO PARKS
TIME WINDOWS
1 1/2 HOURS AFTER SUNRISE TO 1 1/2 HOURS BEFORE SUNSET (ALL YEAR)
10:18 AM TO 4:18 PM (SPRING TO FALL EQUINOX)
11:18 AM TO 2:18 PM (SPRING TO FALL EQUINOX)
1 2 3 4 5 6
HOURS OF SUN ACCESS TO PERIMETER OF PARK
CUMBERLAND PARK
ROSEDALE VALLEY
MOWAT BLOCK
COLLEGE PARK
ALLEN GARDENS
DEVONIAN SQUARE
DUNDAS SQUARE
GRANGE PARK
OSGOODE MALL
TRINITY SQUARE
METROPOLITAN UNITED CHURCH GROUNDS
OSGOODE GARDENS
NATHAN PHILLIPS SQUARE
COURTHOUSE SQUARE
COMMERCE COURT
ROUNDHOUSE PARK
MAPLE LEAF QUAY

Fig. 4.2 Field Study Analysis: Sun Access to Parks in the Central Area.

ceives almost no direct sunlight, except during the late afternoon when the sun's position is aligned with the streets and bathes both sidewalks in sunshine. Fig. 4.1 illustrates that east-west streets ranged from a low of zero to one hour of sun access in September along the built-up portion of Bloor Street, between Bay Street and Avenue Road, to a high of eight hours on Queen Street, between University Avenue and Spadina. The east-west streets studied averaged three to five hours of sunlight, primarily on the northern sides of the street.

The solar-access window of five hours starting at 11:18 a.m. DST in September results in a relationship of street-width to building-height of one to point six (1:0.6). For example, on a 26m street, the building height on the south side at the property line measures 15.5m. If the building height is the same on the north side, the 18-degree shift of the street grid west of north will result in further sun access in summer months, as the sun crosses the axis of the street in the late afternoon, providing direct sun access to the southern side of the street.

In a typical east-west street, with a solar access window of three hours beginning at 12:18 p.m. DST in September, the relationship of street width to street wall height is approximately one to point eight (1:0.8) On a 26m street the building height on the south side at the property line is approximately 21m, the same street-to-building relationship as for five-hour time windows on north-south streets.

General Observations Resulting from the Sunlight Analyses

In general, it is interesting to note that the height-width relationships that are noted for 3- and 5-hour solar access windows on north-south and east-west streets are not unlike similar height standards adopted in Paris and New York. The analysis suggests slightly lower heights of development due to the more northern latitude of Toronto compared to New York. As is apparent from the analysis, dense urban form can be achieved while allowing solar access.

4.1.2 Sunlight for Open Spaces

For parks and open spaces, surveys with fish-eye photography were also undertaken (*Fig. 4.2*). The team has analyzed seventeen open spaces in the Central Area. Seven open spaces are recorded in the recommendation section of this report, each characteristic of a type identified in the Classification of Open Spaces. In reading Fig. 4.2, it is important to note that, although the results are shown as bars aligning the perimeter of the park, the points surveyed were taken at equal intervals along the perimeter of the park and at central or representative locations within the park. While some high buildings surrounding a park may shadow particular areas, the results recorded in Fig. 4.2 are generalized to illustrate the prevailing condition.

It is evident that a large amount of sun access is still available to the Central Area's larger open spaces. It is also evident that smaller urban parks are more vulnerable to losing solar access due to their size and to high-density developments in their vicinity, as is seen at several downtown plazas and other urban open spaces. Even buildings three or four blocks away can cast shadows over open spaces and severely restrict sun access, often during critical hours.

As mentioned above, pedestrians and open space users during spring, fall, and winter depend on sun radiation for thermal comfort. Comfort is particularly important for the enjoyment of open spaces and parks, and one may observe that sunlight is critical for human enjoyment as well as healthy growth of many plants. Parks cannot function in permanent shadow. Yet a number of downtown open spaces such as Commerce Court, and to a lesser degree Trinity Square, are in the shade most of the time. Observation of these spaces clearly demonstrated that these spaces are used when and where there is sunshine and empty where there is none, for all but the hottest summer months.

Larger Open Spaces

The Rosedale Valley Ravine, Allan Gardens, The Grange Park, and Osgoode Gardens fall under the category of large urban open spaces. In most cases at the present, sunlight reaches most of the area at almost all times of the year for most of the day. This results in an average 9-hour duration of sunlight. All of these spaces are planted and provide for a large variety of activities. They are valuable assets for the city, and it is unlikely that many more opportunities to develop open spaces of this size will present themselves in the Central Area. For this reason, it is important that presently available sun access is maintained.

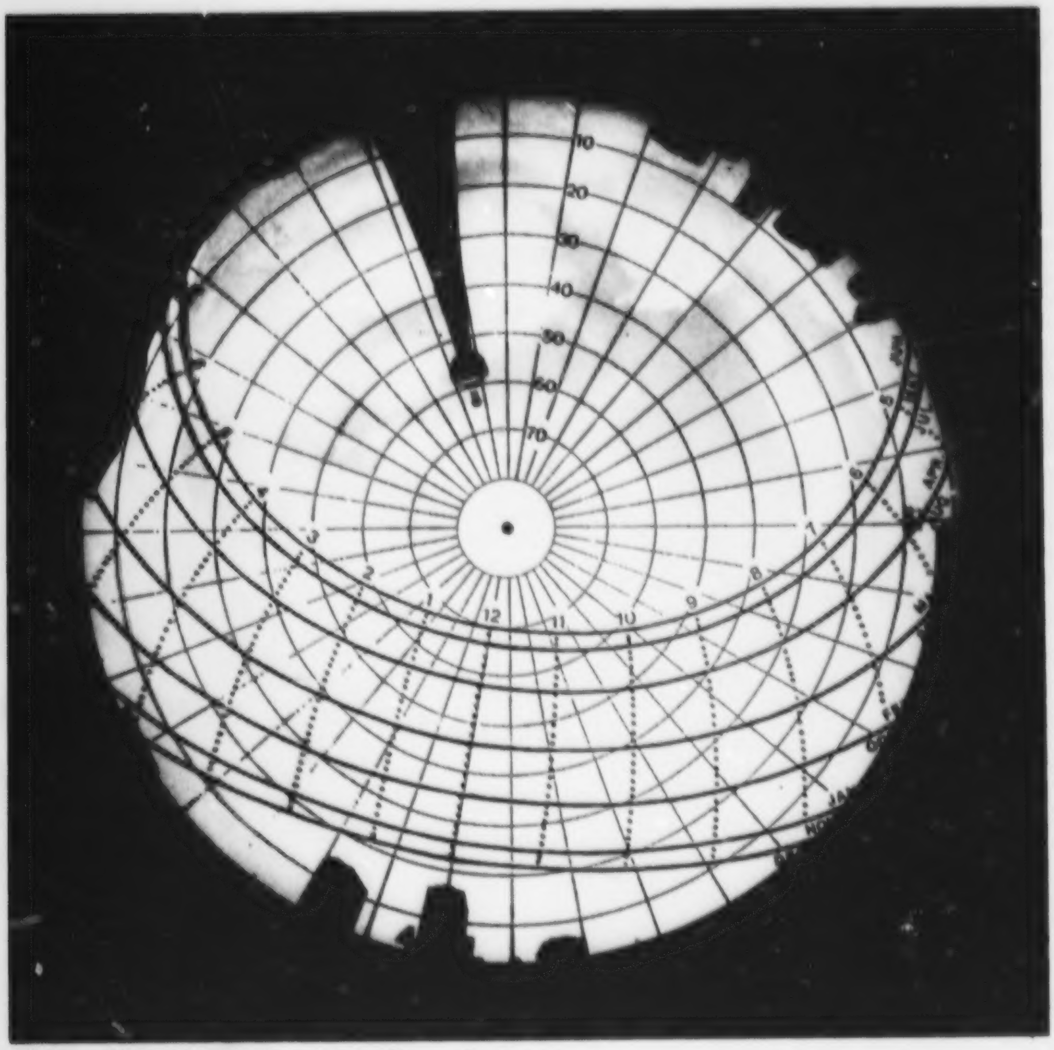
Mid-Size Open Spaces

Trinity Square, College Park, Devonian Square, Nathan Phillips Square, Maple Leaf Quay, Osgoode Mall, and the open space surrounding Metropolitan Church fall under the category of mid-size open spaces. These spaces are typical in their size and association with higher density development. They are representative of the types of spaces that the city may acquire in the future, as, for example, the newly created open spaces in the Railway Lands or in the Ataratiri neighbourhood. The survey conducted indicates that parks in this more developed urban context receive on average six hours of sun access daily. Fortunately the available time of sunlight access is centered around the noon hour, allowing passive recreational use like sitting on a bench, or very active use like ice-skating.

These open spaces exist within a variety of conditions and should be analyzed individually. Specific restrictions should be identified for each space and standards should be set to ensure a minimum duration of sun access during the midday hours. Also, the fish-eye photographs indicated that access to many of these spaces would be seriously impaired if tall buildings were to be erected within two to three blocks to the south, east and west of a given site. The map (Fig.4.2) shows that most midsize open spaces receive six hours of sunlight in the spring and fall.

Small Open Spaces

Many of the small open spaces are enclosed by high buildings. Poor sunlight access is typically observed at these locations. Commerce Court, Court House Square, Cumberland Park, and the potential park site at Dundas Square fall under this category, as well as spaces in the forecourt in front of the Mowat Block on Bay Street. The analysis indicates approximately three hours of sunlight falls on most of these spaces at the fall equinox, September 21st. These spaces are important in providing open space for lunch time users, and it is important to preserve available sun access. Small open spaces are vulnerable to losing whatever little potential sunlight they receive by the shadow of only one or very few buildings nearby. Again, as in the case of the mid-size spaces, specific regulation for each must must be established in order to preserve existing conditions.


10
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JUN
JUL
APR
JAN
NOV

Fisheye View of Sky above Roundhouse Park taken at centerpoint of turntable at the former locomotive roundhouse.

4.2 Laboratory Analysis

The maps presented in this section of the analysis show wind velocities and seasonal comfort conditions for existing, potential, and mitigated development scenarios. This section also includes visual simulation of the existing conditions and the two future development scenarios.

Wind

The results of the wind tunnel analysis are expressed in terms of an "equivalent wind" which combines the effects of mean windspeed, and wind turbulence or gustiness. Using the wind tunnel, it is possible to calculate the ratio between the wind speed at each point on the ground and the wind speed at the weather station from which the wind data is obtained. There is a set of ratios for each wind directon. If, for example, a ratio of 0.5 is measured at a given point in the model for a given wind direction, the wind speed at this point amounts to 50 percent of the wind speed measured at the weather station. For example, the actual wind velocities at a point with a ratio of 0.5 would measure 10 km/hr wind when the wind at the weather station measures 20 km/hr. These wind speed ratios are recorded on the maps in this section of the report. In studying these maps, velocity ratio above 0.8 should be noted. At those points where wind velocities exceed 0.8 along sidewalks, the likelihood of adverse wind conditions for pedestrians is great. For example, if wind velocities exceed 22 km/hr at the weather station, at a point with the ratio of 0.8, the wind speed at street level will amount to 17.6 km/hr. A wind at that speed will be close to the 18 km/hr (exactly 17.7 km/hr or 11 mph) wind speed acceptability criterion for pedestrians (see Section 2, Effects of Mechanical Force of Winds for Pedestrians).

Wind speeds in excess of 22 km/hr are frequently measured at Toronto weather stations, particularly on days with west wind during the winter months and on days with winds coming from the northeast and east in the winter and spring.

In parks and in areas where people sit, attention should be paid to wind velocity ratio of 0.6. Given an acceptability criterion of 11 km/hr (7 mph), the velocity ratio of 0.6 would produce actual wind velocities of 11 km/hr at those times when the wind at the weather station measures 19 km/hr, a wind velocity frequently measured at weather stations during all seasons of the year.

Comfort

The results of the comfort analysis are expressed in terms of percentage of time. For example, the number shown at a given location on one of the seasonal maps indicates the percentage of daylight hours for which such a point would be considered comfortable, where a point with a percentage of less than 41 percent is likely to be too cold most of the time. During the spring and fall, 60 percent is the highest percentage of comfortable time found in the three study areas.

A graphic scale is used to clarify the meaning of the comfort percentages. The range of percentages measured includes points with percentages of 25% to 41%. These points are generally too cold to be comfortable most of the time in the spring and fall during daylight hours. Percentages from 42% to 51% are considered generally comfortable, and

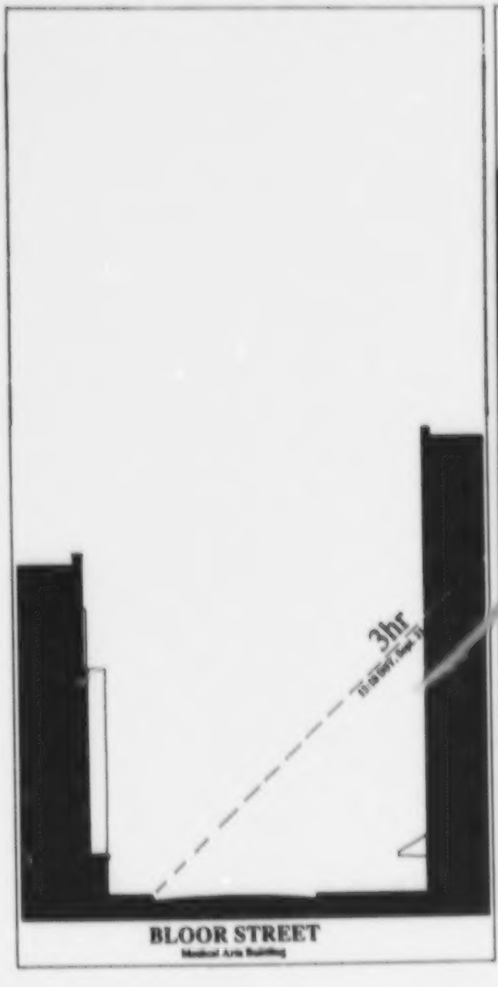
52% to 60% are mostly comfortable. This graphic scale should be interpreted primarily for comfort during the midday hours. Points in the below 42% category are less likely to be comfortable at lunchtime. The middle category indicates points that are likely to be comfortable during the lunch break; the 53% to 60% category indicates points that are likely to be comfortable from mid-morning until the late afternoon hours.

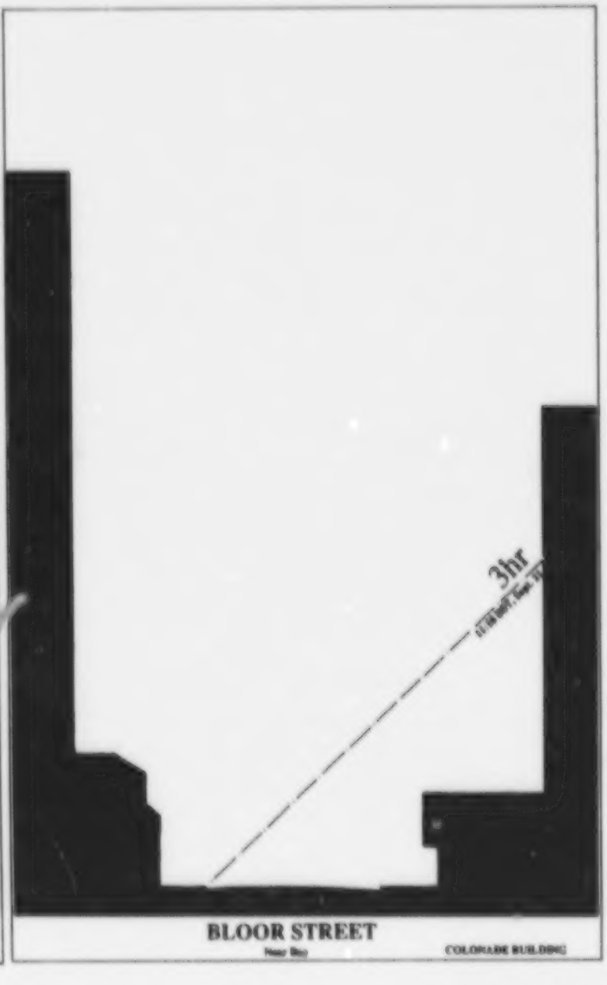
Wind Tunnel Studies, Northwest Wind Comfort Modeling, Spring Season

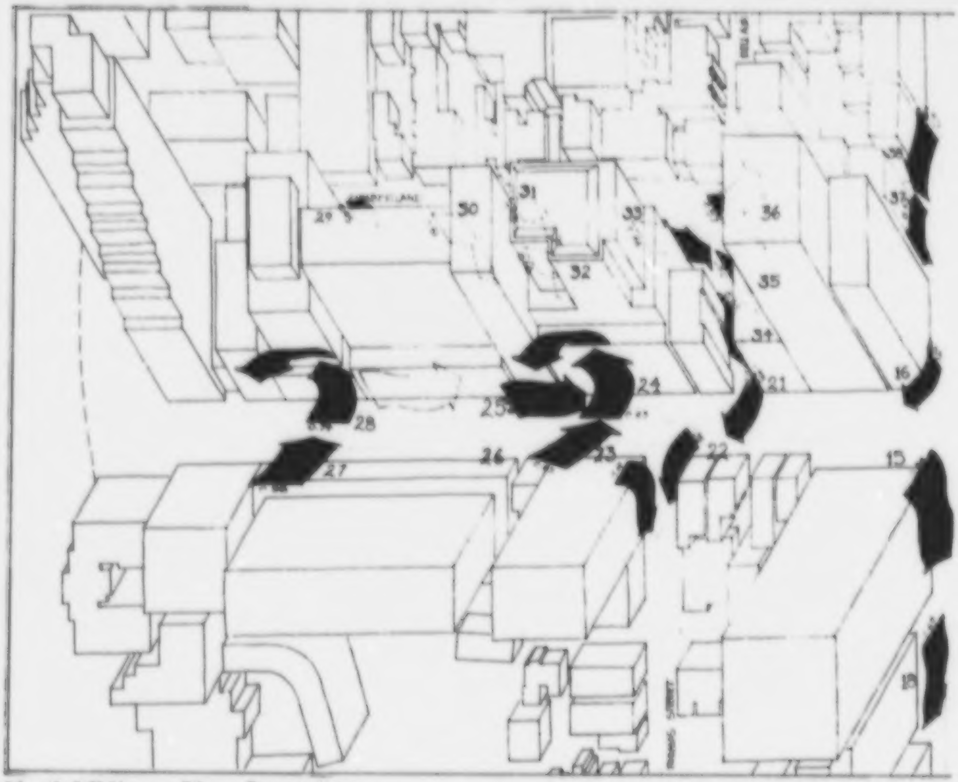
North Midtown, Bloor Street Area

East Downtown

Railway Lands


3hr
BLOOR STREET
Medical Arts Building


3hr
BLOOR STREET
Near Bay
COLONADE BUILDING



North Midtown, Bloor Street Area
Existing Condition, Northwest Wind

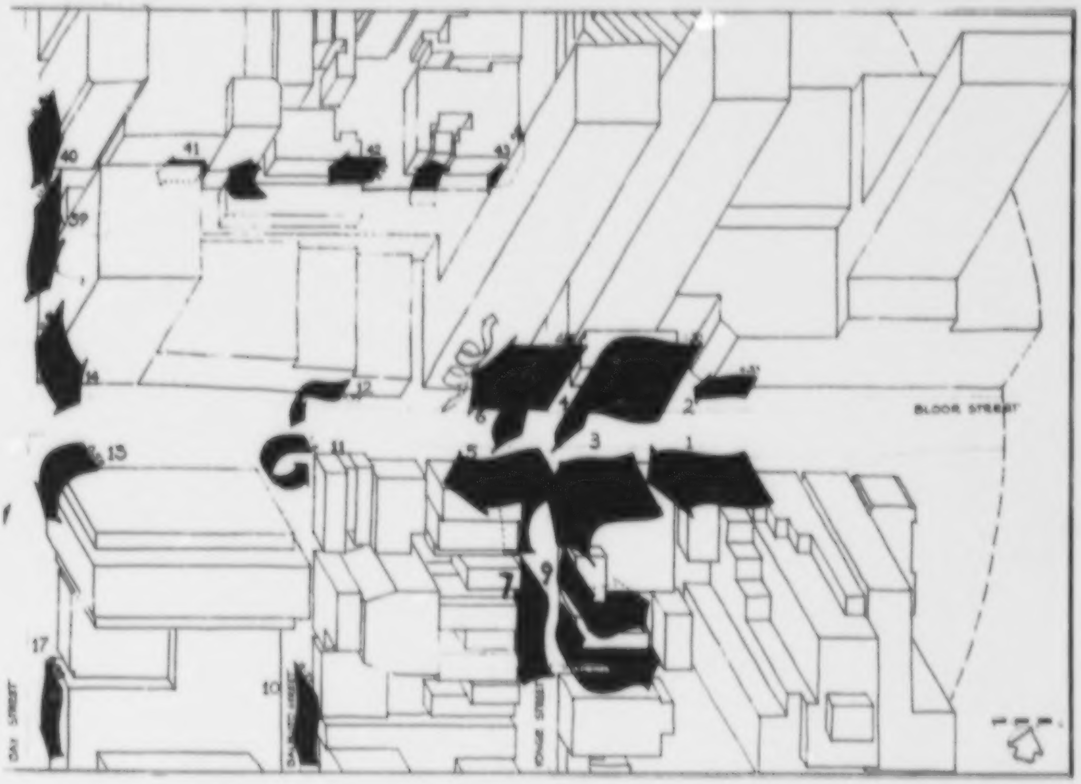
4.2.1 North Midtown, Bloor Street Area

Wind
The wind velocities under the existing conditions are high to very high along Bloor Street between Avenue Road and Yonge Steet. The intersection at Bloor and Yonge is extremely windy (1.50) on days with northwest winds.

There are only a few places along Bloor Street where pedestrians are sheltered from the wind. Cumberland Street, one block to the north of Bloor Steet is somewhat sheltered. Here wind velocity ratios range between 0.40 and 0.80. The most windy corners are at Bay Steet (0.85) and at Bellair Street (0.66). The parking lot on CumberlandStreet west of Bellair Street is slated for a park. Here velocity ratios of 0.45 to 0.66 would make the future park only moderately sheltered. (On days with winds from the east the park would be sheltered).

Other streets and parks analyzed but not shown on the map above include Yorkville Avenue and Ketchum Park. The wind velocities on Yorkville Avenue are lower than those measured on Cumberland Steet. In Ketchum Park along its southern edge winds exceed the 0.6 threshold.

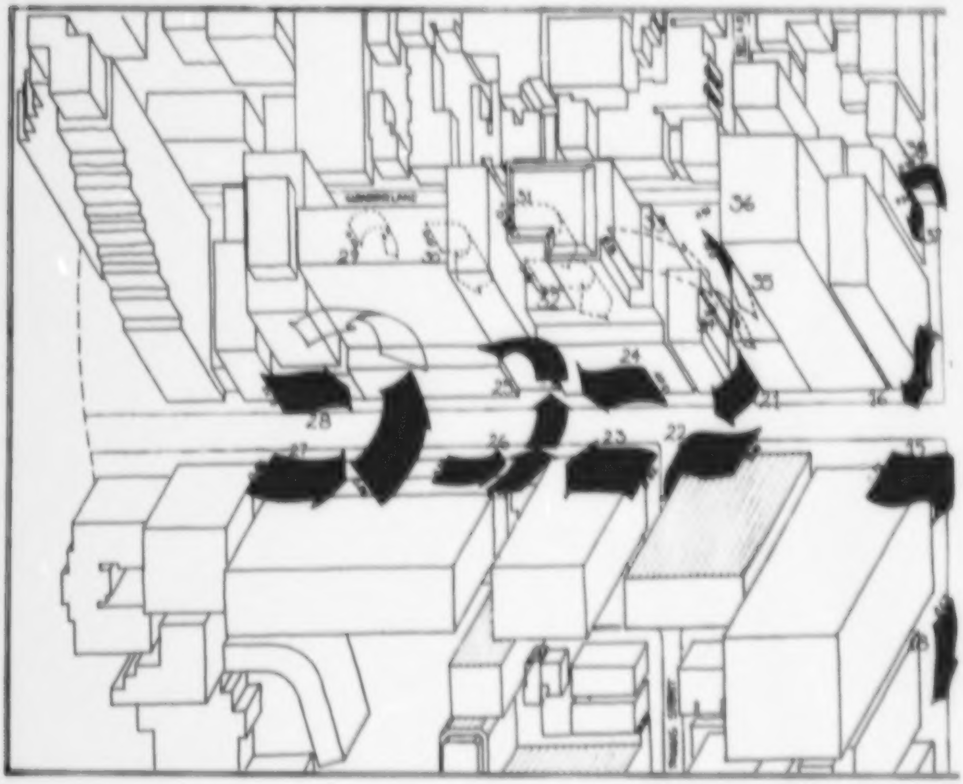
In total, the North Midtown has twelve sidewalk points indicating wind velocity ratios in excess of the 0.8 threshold.



Wind Tunnel Measurement Results

Existing Conditions

Pt. No.	Wind Ratio NW	W	SW	E
1	1.088	1.163	0.149	0.898
2	0.385	0.998	0.228	1.091
3	1.105	0.617	0.253	0.52
4	1.495	1.206	0.324	0.877
5	0.941	0.832	0.206	0.441
6	1.276	0.787	0.318	0.691
7	0.768	0.661	0.354	0.704
8	0.949	0.639	0.318	0.652
9	0.775	0.526	0.41	0.716
10	0.714	0.38	0.656	0.528
11	0.401	0.387	0.321	0.267
12	0.372	0.344	0.445	0.716
13	0.581	0.676	0.534	0.611
14	0.699	0.387	0.81	0.715
15	0.903	0.738	0.454	0.921
16	0.426	0.523	0.871	0.72
17	0.593	0.675	0.652	0.554
18	0.685	0.378	0.476	0.775
19	0.508	0.403	0.651	0.523
20	0.389	0.503	0.723	0.821
21	0.553	0.332	0.369	0.646
22	0.345	0.507	0.527	0.493
23	0.48	0.555	0.422	0.341
24	0.631	0.669	0.673	0.436
25	0.638	0.709	0.782	0.296
26	0.597	0.688	0.66	0.461
27	0.865	1.131	0.87	0.226
28	0.743	0.884	0.884	0.227
29	0.454	0.543	0.686	0.263
30	0.4	0.341	0.471	0.301
31	0.559	0.571	0.337	0.247
32	0.668	0.586	0.478	0.259
33	0.525	0.597	0.627	0.288
34	0.607	0.372	0.527	0.256
35	0.631	0.335	0.778	0.242
36	0.571	0.454	0.298	0.306
37	0.318	0.581	0.361	0.57
38	0.503	0.627	0.376	0.552
39	0.853	0.792	0.429	0.39
40	0.812	0.735	0.292	0.452
41	0.384	0.472	0.264	0.626
42	0.447	0.271	0.266	0.351
43	0.369	0.352	0.363	0.389
44	0.552	0.336	0.295	0.819
45	0.402	0.386	0.472	0.641
46	0.644	0.683	0.368	0.524
47	0.561	0.568	0.364	0.549
48	0.418	0.395	0.241	0.362



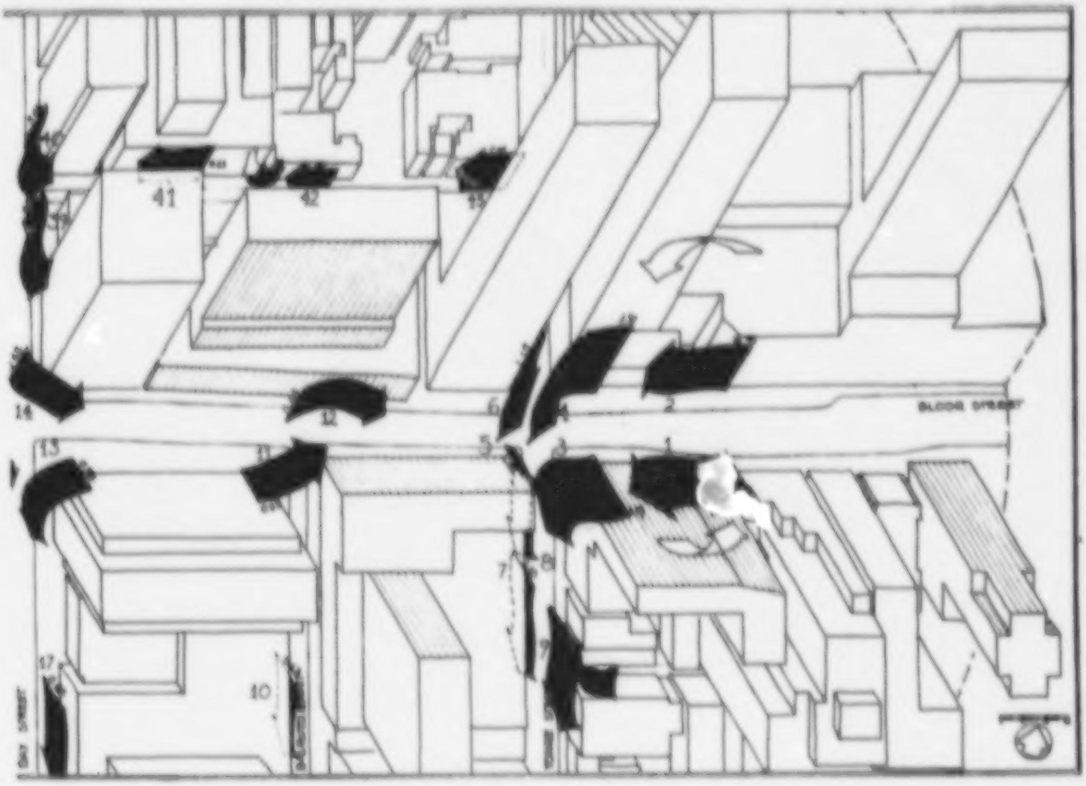
North Midtown, Bloor Street Area
Potential Condition, Northwest Wind

Potential development along Bloor Street results in higher wind velocities. At points where wind velocities of 0.35 to 0.40 had been measured under existing conditions, potential development would increase wind speeds in some places above the 0.8 threshold (Compare points 22 and 23 and also points 11 and 12).

The wind velocities along Cumberland Street and in the future Cumberland Park remain unchanged.

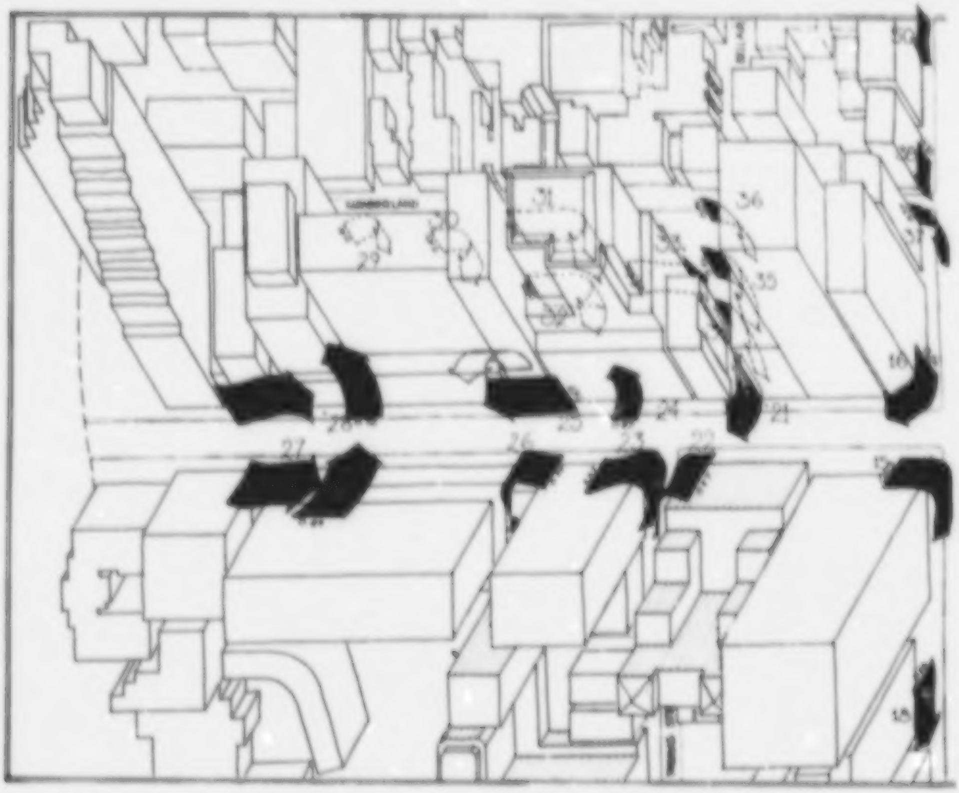
Yorkville Avenue, two blocks to the north of Bloor Street (not shown on the map) is made more windy at the intersection with Bay Street if a 30m to 46m high building were to be constructed. (Velocities increased from 0.24 and 0.40 to 0.92 and 0.72).

In total, in the North Midtown Area, the number of points on sidewalks where velocitiy ratios above 0.80 were measured increased to 17 under potential development. In parks the number of points with velocity ratios above 0.60 remained approximately the same.



Potential Development

Pt. No. Wind Ratio	NW	W	SW	E
1	1.002	1.205	0.231	0.632
2	0.959	1.026	0.347	0.57
3	1.147	0.515	0.481	0.354
4	1.314	0.271	0.409	0.564
5	1.059	0.545	0.259	0.451
6	1.147	0.805	0.446	0.411
7	1.098	0.589	0.417	0.549
8	1.086	0.65	0.196	0.448
9	0.98	0.557	0.443	0.505
10	0.629	0.343	0.645	1.096
11	0.679	0.513	0.5	0.794
12	0.629	0.431	0.258	0.931
13	0.576	0.481	0.517	0.832
14	0.629	0.553	0.502	0.733
15	0.975	0.681	0.534	1.017
16	0.467	0.481	0.519	0.858
17	0.602	0.497	0.621	0.546
18	0.67	0.27	0.337	1.041
19	0.454	0.603	0.731	0.771
20	0.415	0.652	0.877	0.765
21	0.805	0.25	0.776	0.685
22	0.942	0.522	0.692	0.489
23	0.815	0.556	0.515	0.404
24	0.689	0.671	0.763	0.506
25	0.537	0.681	0.856	0.359
26	0.516	0.742	0.753	0.415
27	0.856	1.107	0.872	0.209
28	0.732	0.884	0.914	0.223
29	0.427	0.581	0.714	0.265
30	0.61	0.364	0.574	0.26
31	0.612	0.579	0.482	0.304
32	0.653	0.588	0.516	0.191
33	0.76	0.543	0.561	0.289
34	0.61	0.358	0.376	0.231
35	0.906	0.434	0.458	0.3
36	0.537	0.428	0.355	0.257
37	0.342	0.46	0.48	0.654
38	0.373	0.691	0.552	0.53
39	0.67	0.801	0.605	0.512
40	0.658	0.852	0.594	0.544
41	0.631	0.674	0.164	0.266
42	0.383	0.23	0.144	0.282
43	0.684	0.423	0.189	0.691
44	0.358	0.53	0.565	0.773
45	0.338	0.527	0.622	0.603
46	0.539	0.637	0.761	0.331
47	0.576	0.753	0.826	0.371
48	0.682	0.47	0.572	0.359

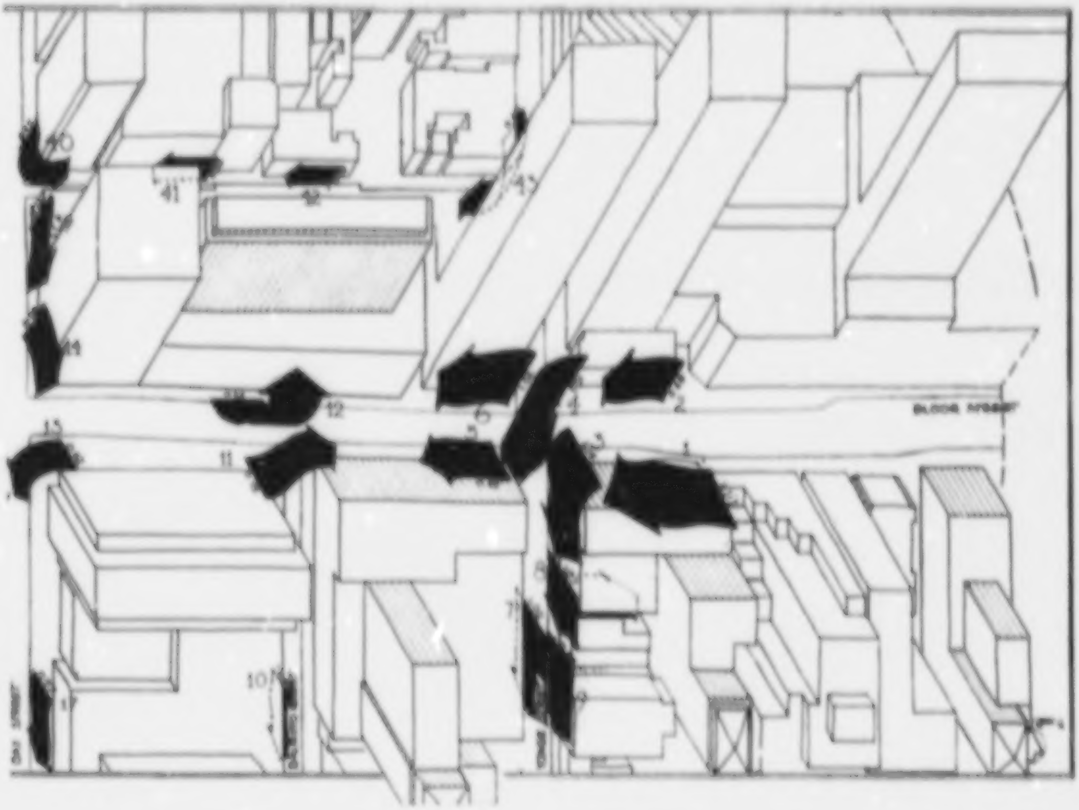


North Midtown, Bloor Street Area
Mitigated Condition, Northwest Wind

Along Bloor Street sidewalk winds would measure almost as strong under mitigated development as they would under potential development. Under mitigated conditions, the new building at St. Thomas and Bloor Streets (points 22 and 23) would provide only somewhat improved wind conditions when compared with a new building under potential development.

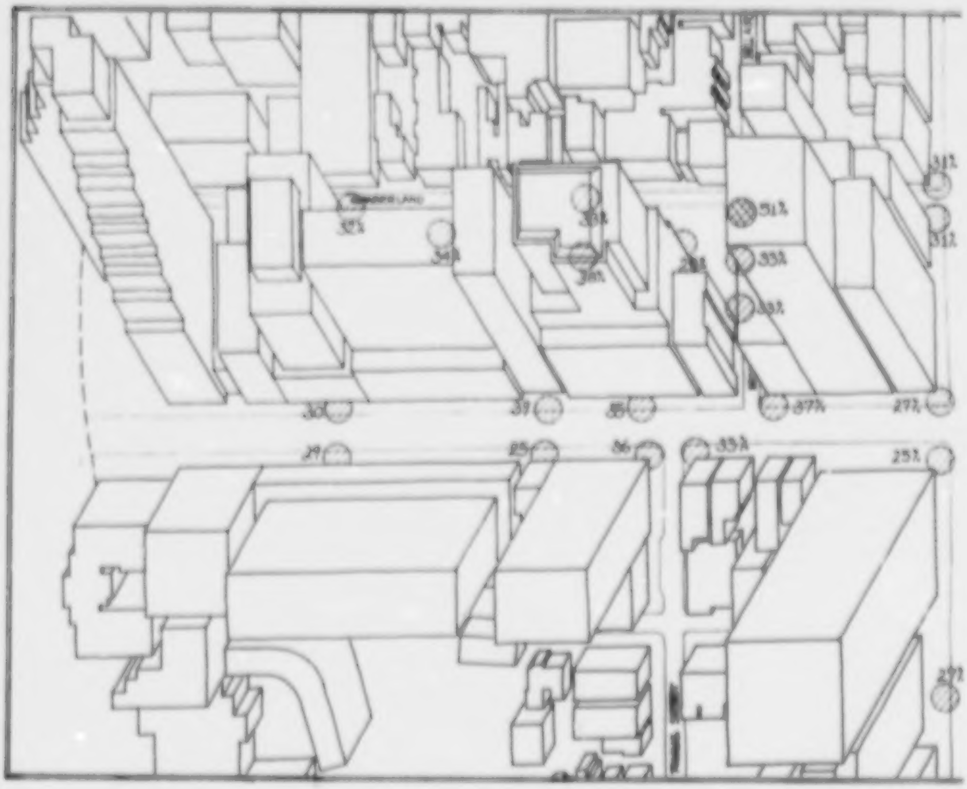
It appears any new developments along Bloor Street would increase the channeling of the already high existing wind velocities. At the extemely windy intersection of Bloor and Yonge streets, the number of points with velocity ratios above 1.00 has been reduced from 7 to 5. Mitigation measures have proven more successful along other streets in the study area.

Overall, the number of points where velocity ratios above 0.80 were measured has decreased to 11 from 17 under potential development. The number of points in parks with ratios above 0.60 remained at 7.



Mitigated

Pt. No.	Wind Ratio NW	W	SW	E
1	1.267	1.046	0.252	0.642
2	0.678	0.912	0.432	0.703
3	1.135	0.825	0.396	0.48
4	1.314	0.348	0.388	0.789
5	0.935	0.549	0.331	0.557
6	1.017	0.618	0.46	0.552
7	1.019	0.461	0.42	0.732
8	1.071	0.528	0.119	0.62
9	0.846	0.463	0.295	0.718
10	0.539	0.226	0.597	0.886
11	0.754	0.432	0.233	0.68
12	0.919	0.29	0.216	0.953
13	0.624	0.553	0.507	0.459
14	0.681	0.478	0.41	0.758
15	0.53	0.635	0.454	0.926
16	0.6	0.458	0.58	0.617
17	0.571	0.495	0.641	0.535
18	0.662	0.335	0.39	0.926
19	0.454	0.485	0.518	0.862
20	0.32	0.542	0.677	0.634
21	0.775	0.471	0.756	0.633
22	0.969	0.406	0.429	0.439
23	0.672	0.479	0.449	0.279
24	0.473	0.611	0.654	0.491
25	0.69	0.617	0.808	0.358
26	0.636	0.605	0.704	0.27
27	0.887	0.982	0.877	0.221
28	0.721	0.777	0.945	0.208
29	0.41	0.511	0.701	0.224
30	0.429	0.333	0.526	0.279
31	0.517	0.529	0.46	0.202
32	0.565	0.503	0.49	0.19
33	0.596	0.538	0.524	0.222
34	0.549	0.314	0.384	0.229
35	0.598	0.387	0.425	0.314
36	0.396	0.429	0.342	0.286
37	0.371	0.565	0.46	0.595
38	0.321	0.596	0.517	0.391
39	0.684	0.755	0.51	0.341
40	0.669	0.771	0.584	0.473
41	0.552	0.571	0.135	0.286
42	0.388	0.233	0.16	0.386
43	0.631	0.37	0.266	0.795
44	0.43	0.448	0.436	0.765
45	0.394	0.451	0.632	0.675
46	0.314	0.396	0.655	0.491
47	0.454	0.565	0.77	0.372
48	0.693	0.361	0.318	0.487



North Midtown, Bloor Street Area
Existing Condition

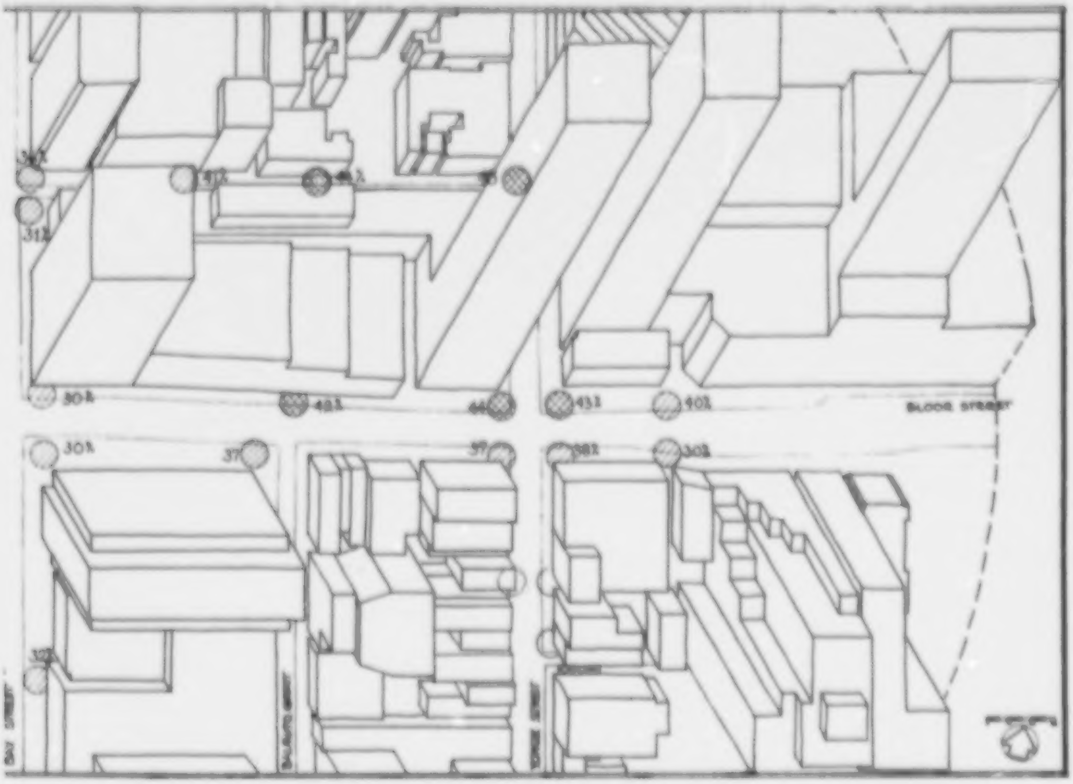
Comfort Scale

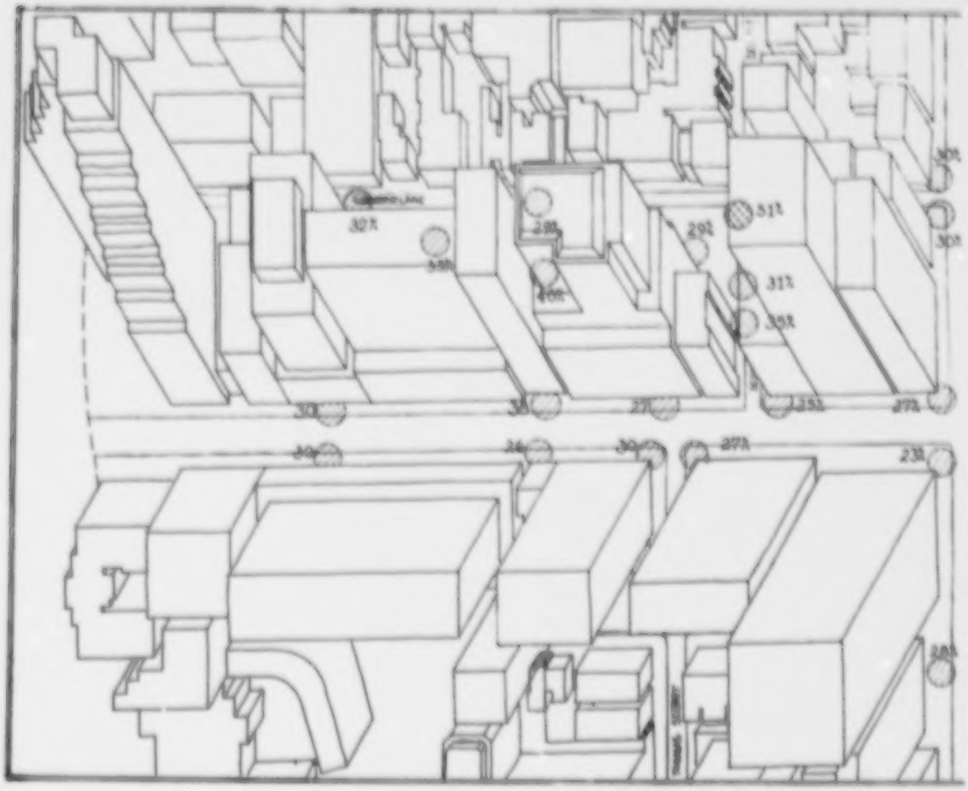
25%-41%	42%-51%	52%-60%
▨	▩	●

4.2.1 North Midtown, Bloor Street Area

Comfort in Spring

Under existing spring conditions, two-thirds of the points tested are too cold to be comfortable. The contrast in building heights between the Yorkville area and Bloor Street produces a wide variation between wind and sun conditions and produces worsening conditions on Bloor. Generally, all but four of the points on Bloor Street are too cold to be comfortable, whereas the streets and parks from Yorkville Street north are usually comfortable. The potential park site on Cumberland Street is comfortable approximately 30% of the time during daylight hours.


31%
30%
40%
44
43%
40%
BLOOR STREET
30%
37
37
38%
30%
32%
BAY STREET
BALMUTO STREET
YONGE STREET

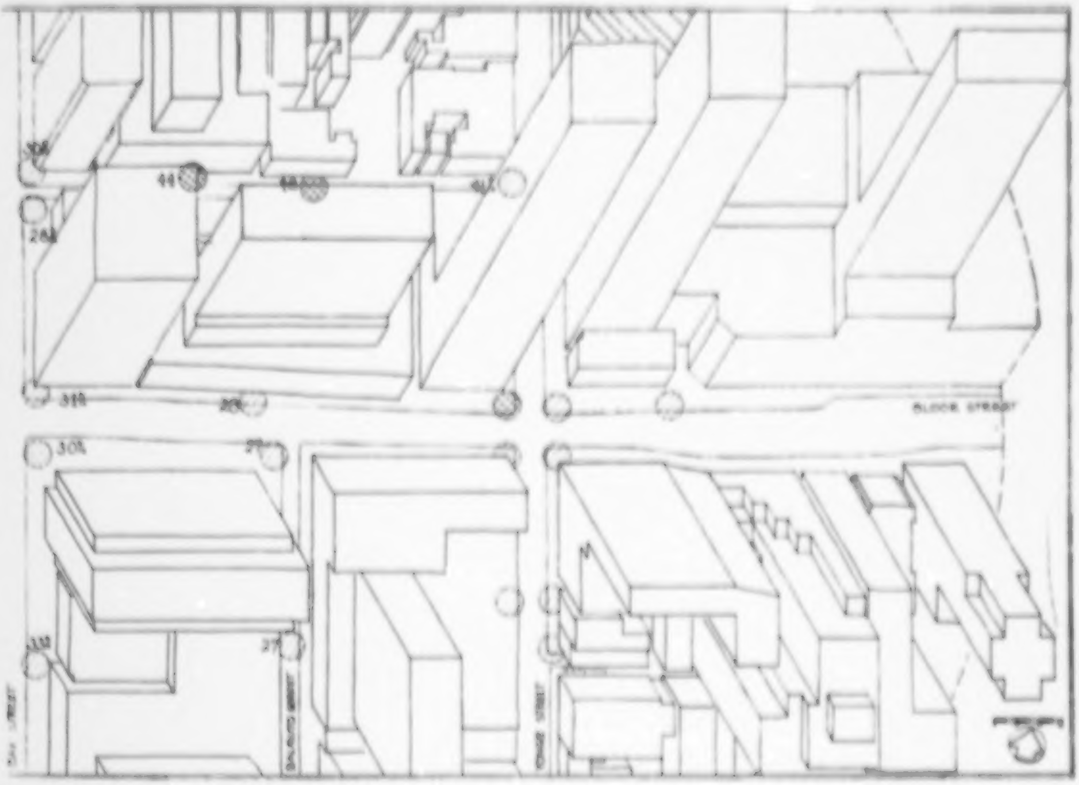


North Midtown, Bloor Street Area
Potential Condition, Spring Comfort

When potential development under current regulations is modeled, conditions are slightly cooler and less comfortable. All but one of the points on Bloor Street are now uncomfortably cold most of the time. Bloor Street sidewalks would only be comfortable between 27% and 30% of the time. Several more points on Yorkville Street east of Bay would have colder conditions if buildings up to 30m were built along Bay Street.

Comfort Scale

25%-41%	42%-51%	52%-60%
▨	▩	●


30%
44
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31%
20%
BLOOR STREET
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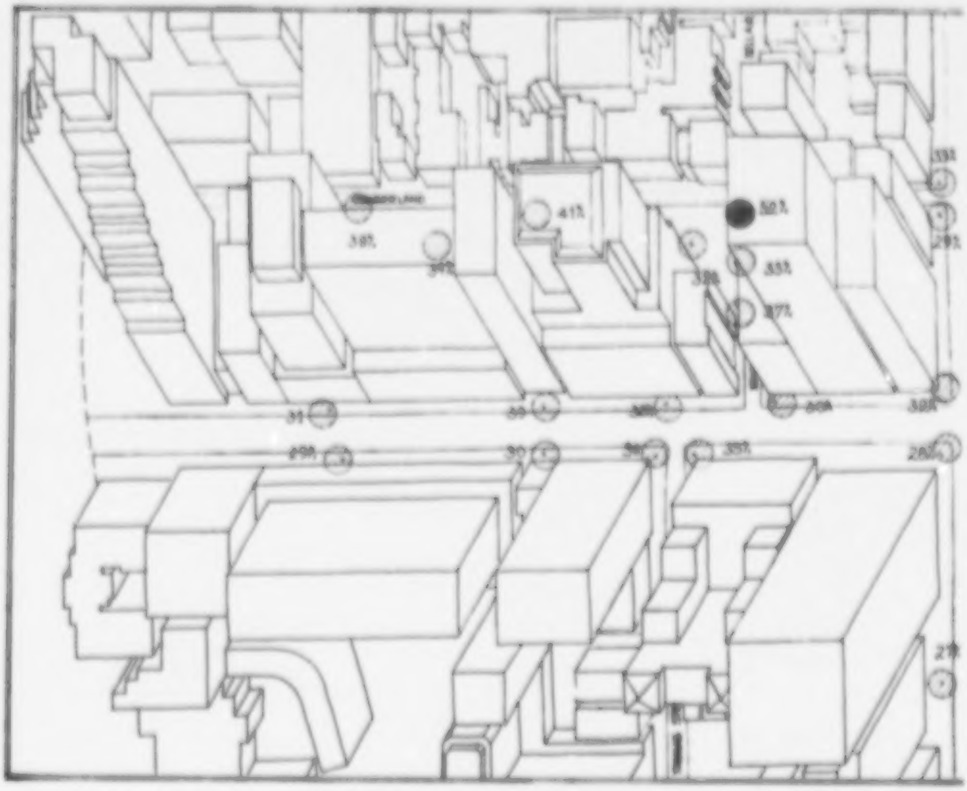
BAY STREET
BALMUTO STREET
YONGE STREET

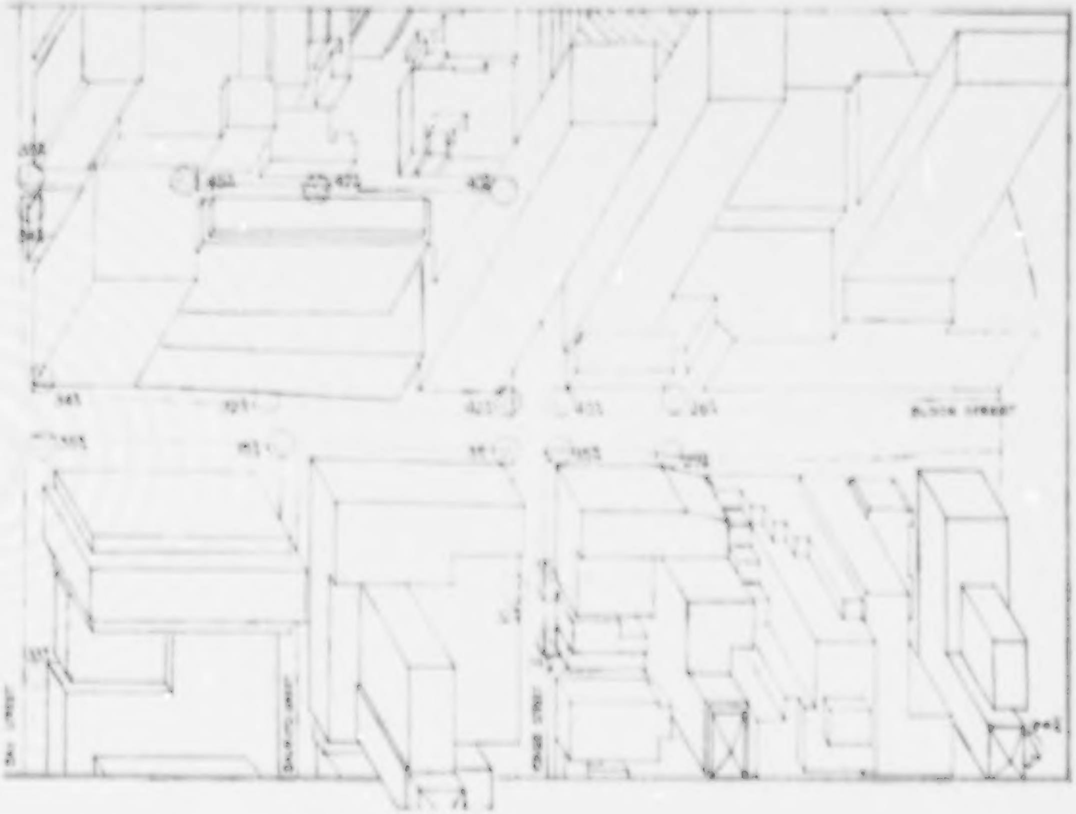


North Midtown, Bloor Street Area
Mitigated Condition, Spring Comfort

Development under the mitigated scenario would increase the duration of sunlight near the intersection of St. Thomas (Bellair Street) with Bloor Street and at Balmuto Street, Yonge Street with Bloor Street. These sidewalks would be more comfortable under the mitigated development than under the potential. Comfort conditions along Yorkville Avenue, east of Bay (not shown on the map), would imprive under the mitigated scenario.

Comfort Scale

25%-41%	42%-51%	52%-60%
▨	▩	●


BUSH STREET

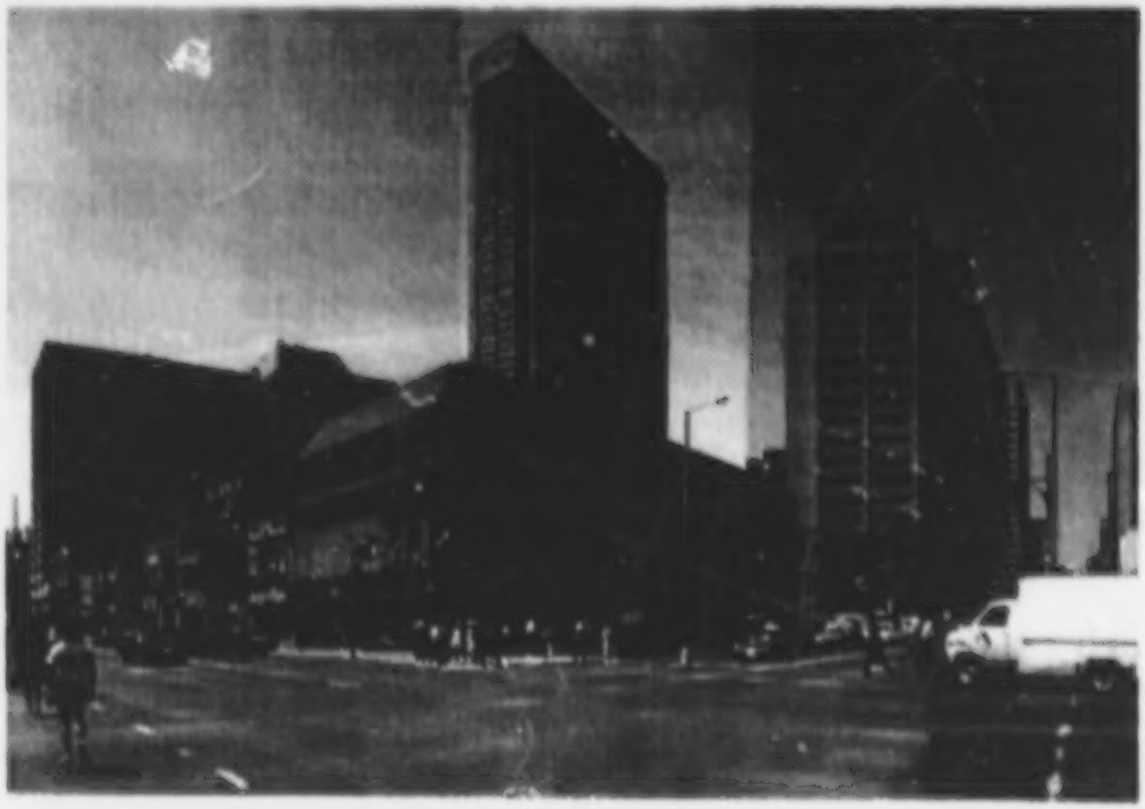


Fig 4.3.a Yonge Street Existing Condition

Built Form

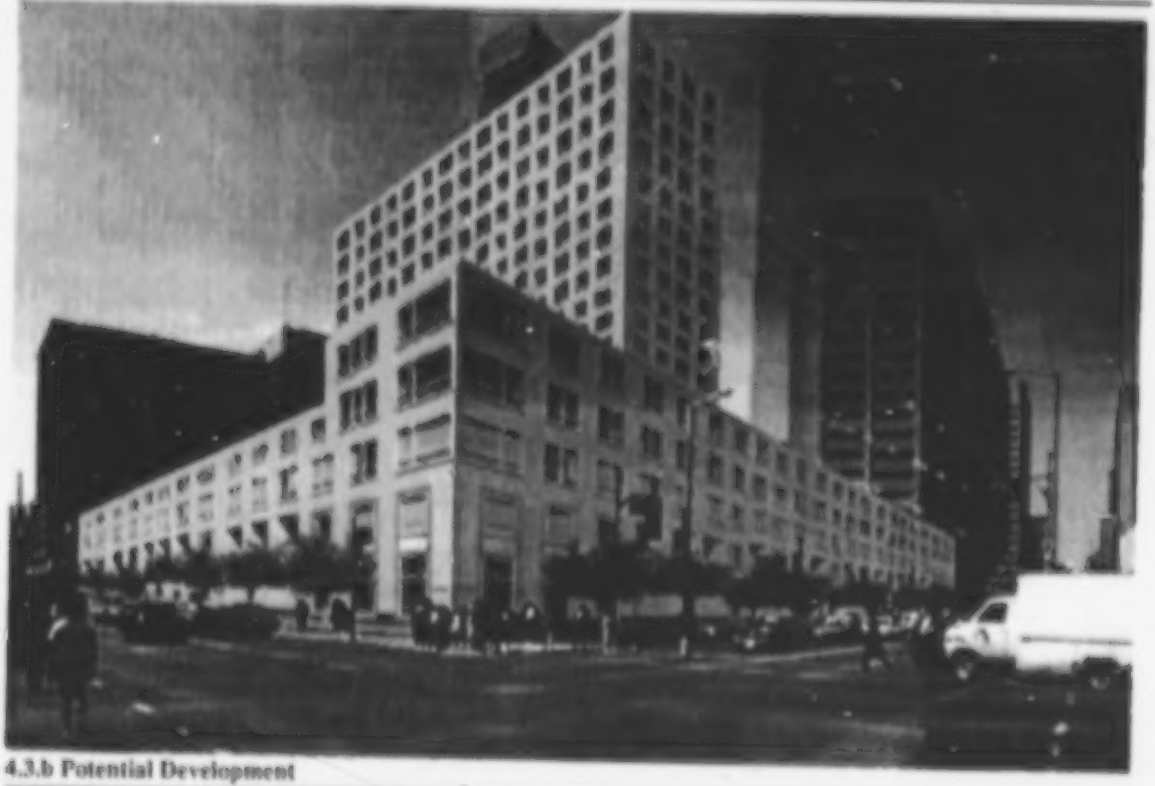
A computer simulation technique was used to simulate the visual effect of each hypothetical development scenario on the experience of walking or driving along Toronto streets. At the intersection of Bloor and Yonge Streets, at the southwestern corner, a set of low-rise commercial buildings front Bloor Street as well as Yonge Street.

Potential Development

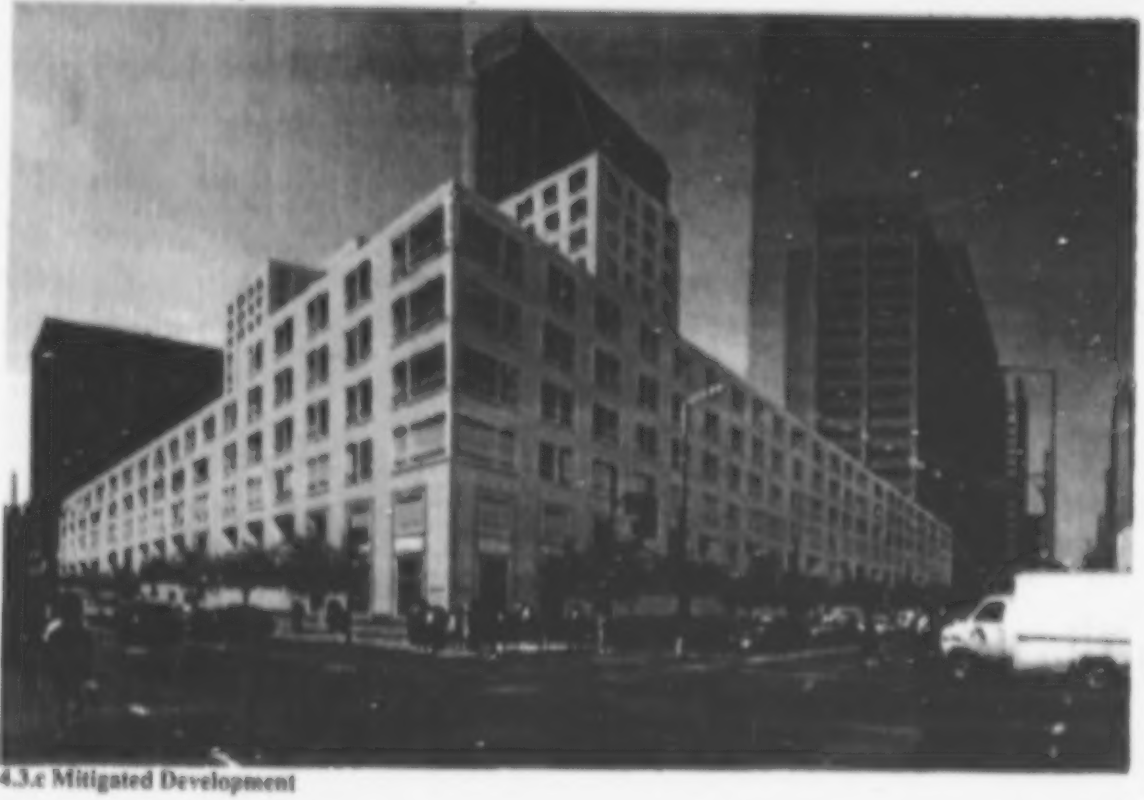
This site, if assembled, could potentially house a large-scale mixed-use development with a podium of four floors along Yonge Street, and a somewhat higher podium of five floors along Bloor Street. Above the four-story podium, a 16- to 18-story (depending on floor-to-ceiling heights) residential tower with an north-south orientation could be built up to the height limit of 61m.

Mitigated Development

The approximate same coverage can be achieved in the mitigated scenario. The podium portion of this hypothetical development would be higher, five floors on Yonge Street and six floors of Bloor Street. Above the five-story podium, an L-shaped tower of 12 to 15 floors could be built (depending on floor to ceiling heights). The height of this tower would be approximately 10m below the Bloor Street height limit of 61m.. The revised height limit would be defined by two sun access planes: the Yonge Street sun access plane of 44 degrees above the streetwall of 16m and the 44-degree sun access plane on Bloor Street above a 20.5m streetwall. The 61m Bloor Street height limit would be reached only at the far southwest corner of this lot.



4.3.b Potential Development



4.3.c Mitigated Development

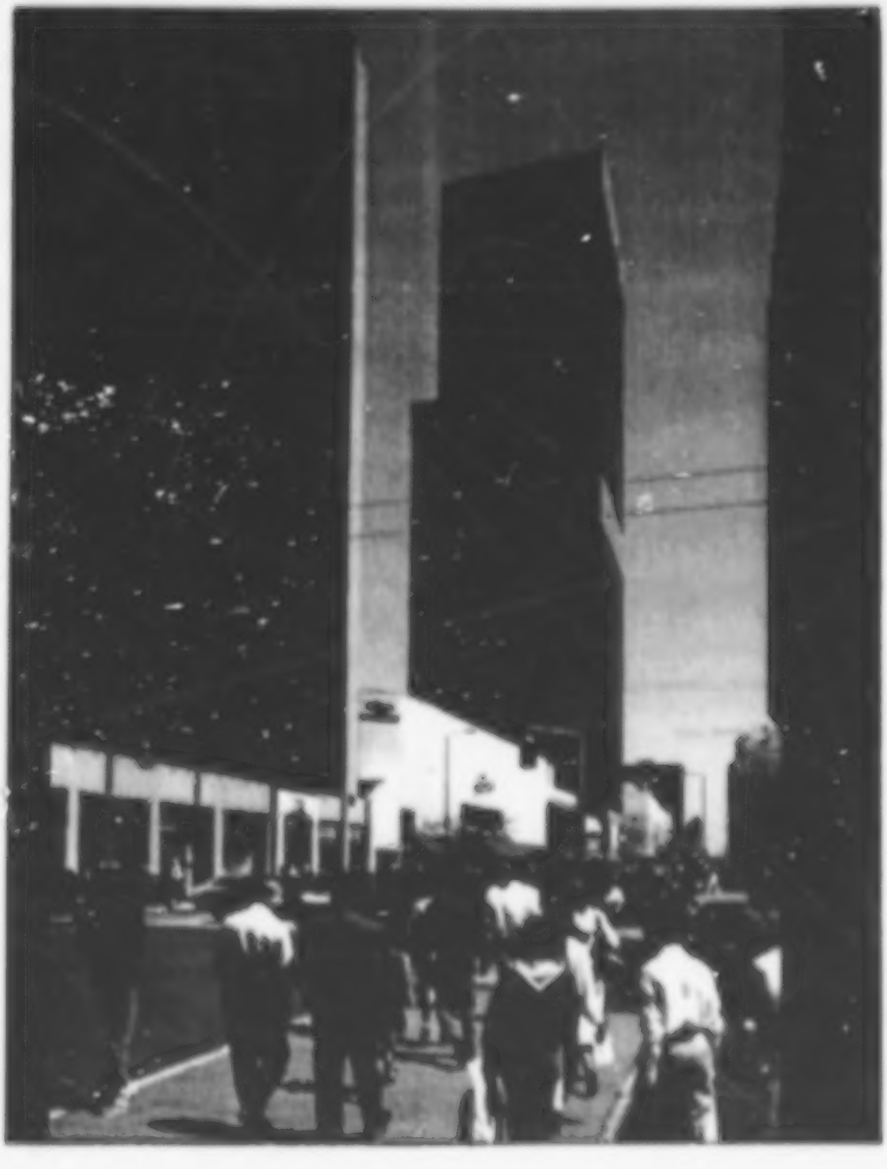


Fig 4.4.a Existing Condition

The sequence of simulations shown in Figs. 4.4a to 4.4c display the site of the Holt Renfrew store on the north side of Bloor Street between Bay and Yonge Streets. In our hypothetical modeling of the potential development, we assumed that a three-story podium with a east-west oriented tower portion would be built. The mitigated scenario displays the same basic configuration. The placing of the tower is not affected by sun access consideration for Bloor Street sidewalks; for obvious reasons, buildings on the north side of east-west streets do not cast shadows during the midday period. They do, however, if tall enough, cast shadows on streets that are located to the north of such a tower, in our case Cumberland Street. The considerations for sunlight to Cumber-

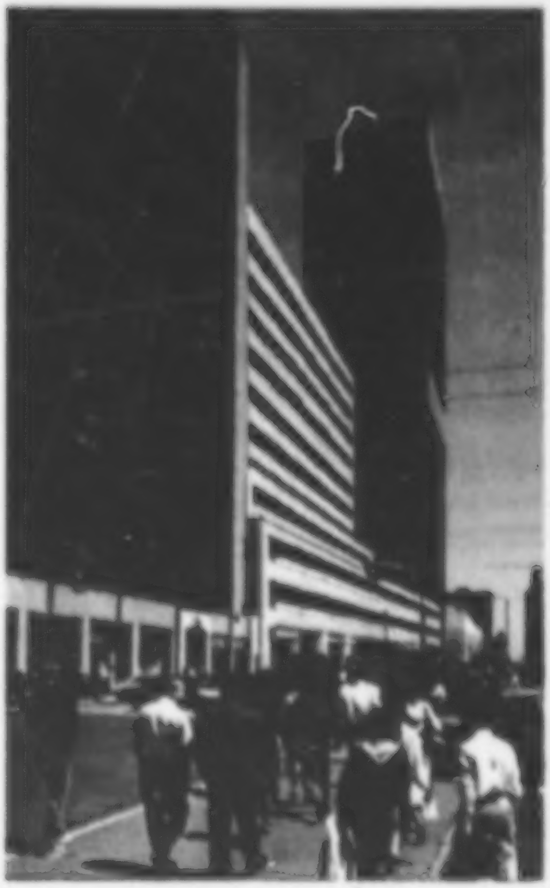


Fig 4.4.b Potential Development

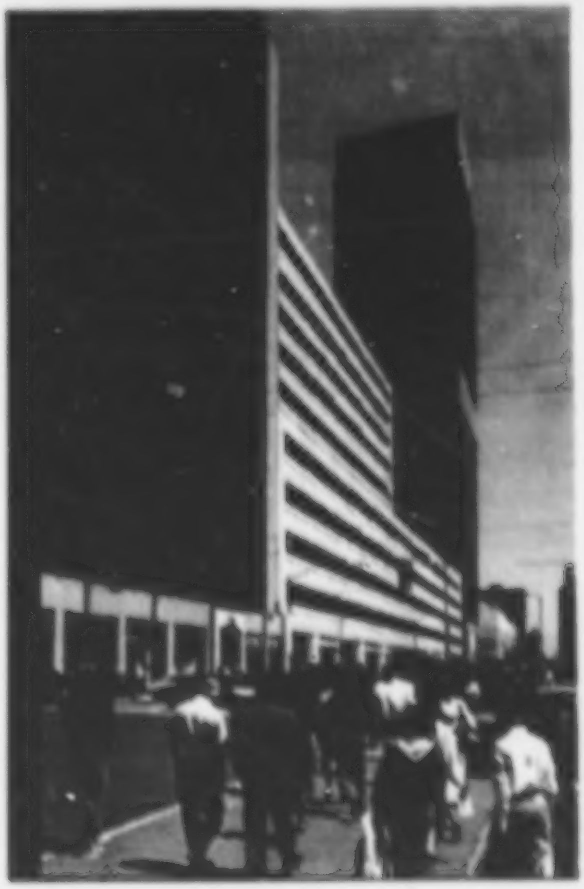


Fig 4.4.c Mitigated Development

land required a slight lowering of the tower and a placement that is somewhat closer to Bloor Street. The exact setback of the tower should also take into consideration the wind velocities at sidewalk level. In our modeling, we observed a minimum tower setback of six meters above the podium. The height of the podium on the north side of east-west streets was modeled to correspond to the streetwall height set by sun access planes for the south side of east-west streets.

The results of the windtunnel studies indicated that, in this case, such a setback of 6m is not enough to mitigate the force of the wind. A ratio of 0.92 was measured for the northwest wind direction compared to 0.37 under the existing condition, and 0.67 under the potential development. In the mitigation scenario, the wind velocity increased at the foot of the building. This analysis indicated that the built form of a future development on this site would need to follow other considerations than those used in the modeling shown here. The setback of the tower above the podium would need to be increased resulting in a lower height of the tower. The already windy conditions on this section of Bloor call for very careful wind tunnel studies of all future developments.

4.2.2 East Downtown

Wind

Existing Conditions
This area of the city is sheltered from west and southwest winds and partially sheltered from the northwest winds by the concentration of tall buildings in the downtown core. With the existing conditions, prevailing northwest winds are generally comfortable, but pedestrians will experience adverse conditions at a few locations. The area considered for a possible park at Dundas Square(not shown on the map) will be windy only part of the time, with wind ratios of 0.71 to 0.80 and as high as 0.98 for the west wind. Only when the wind is from the southwest does this potential park site have more moderate wind ratios.
In the entire area under Northwest Wind conditions only one point measured wind velocity ratios above the 0.80 threshold.

Potential Development
When the developable sites are built out to what is possible under current planning regulations, two places experience adverse conditions. First, the corner of Shuter and Mutual would have wind ratios of 0.73 to 0.93. Here, the wind is funnelled between the proposed tower on the northwest corner and the approved tower on the southwest corner. When the wind blows from other directions, existing and potential conditions are similar at this site, although winds will still be unpleasant for pedestrians. Likewise, the intersection of Shuter and Dalhousie Street would be windy if the 46m tall building on Shuter Street were to be constructed.

At nine sidewalk points the wind velocity ratios measured above the 0.80 threshold.

Mitigated Development
Development under the mitigated scenario would create wind conditions close to what currently exists. At the corner of Shuter and Mutual Streets, some observations noted winds below the existing levels.

Only 2 points measured wind velocity ratios above the 0.80 threshold.

Site 1 Existing Conditions

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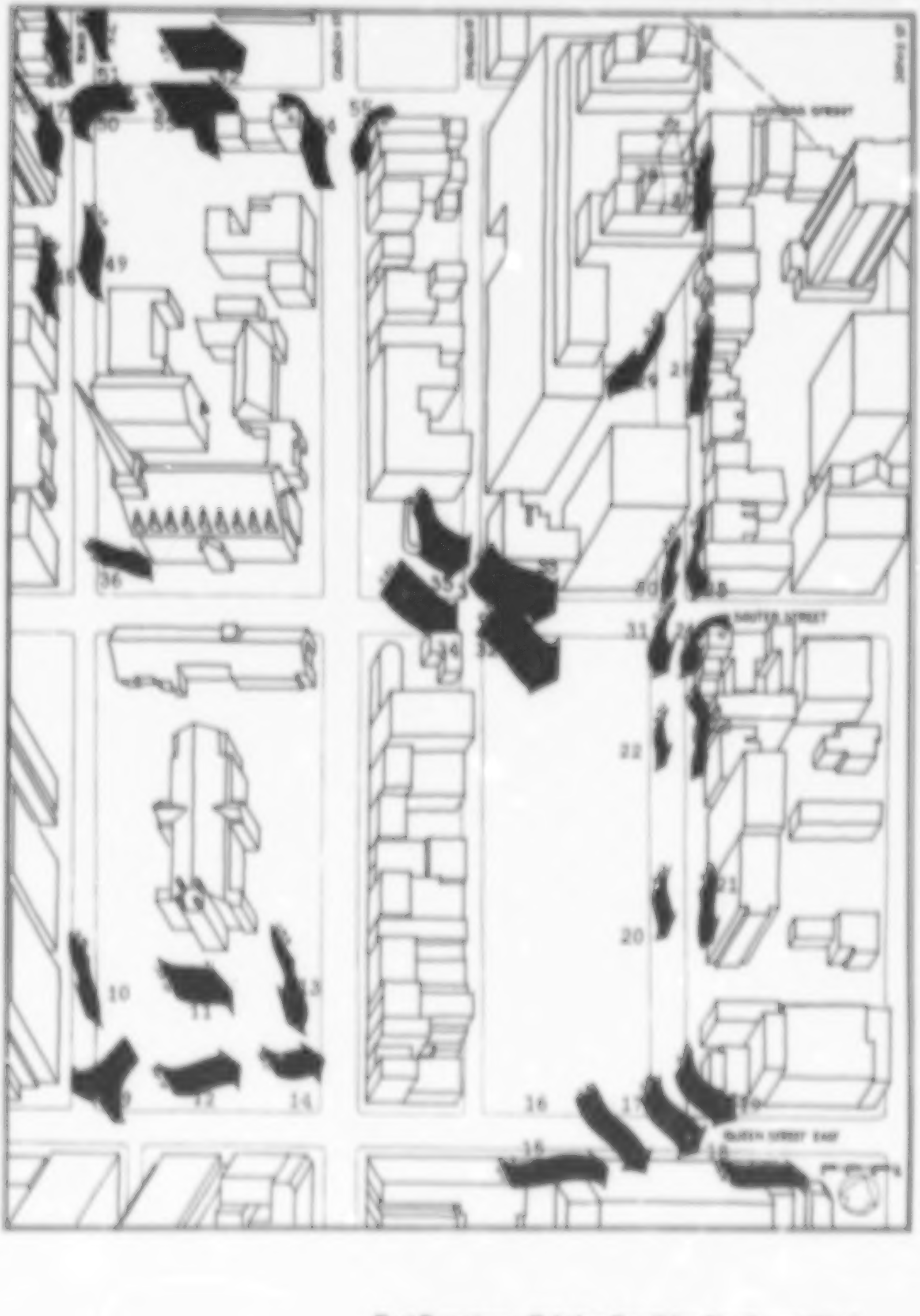
Site 1 Potential Development

[illegible]

Site 1 Mitigated

[illegible]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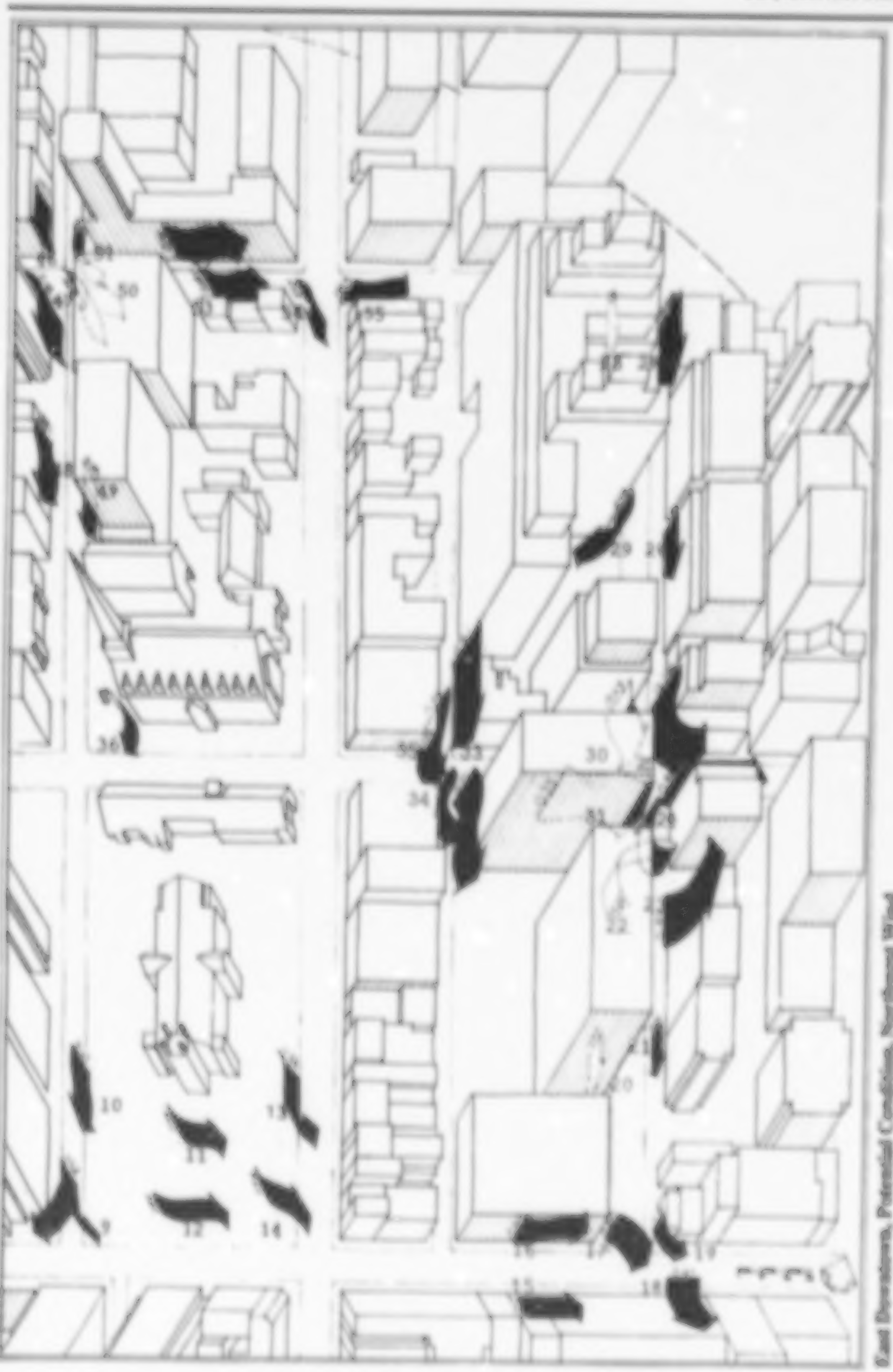
QUEEN STREET EAST

East Downtown, Existing Condition,Northwest Wind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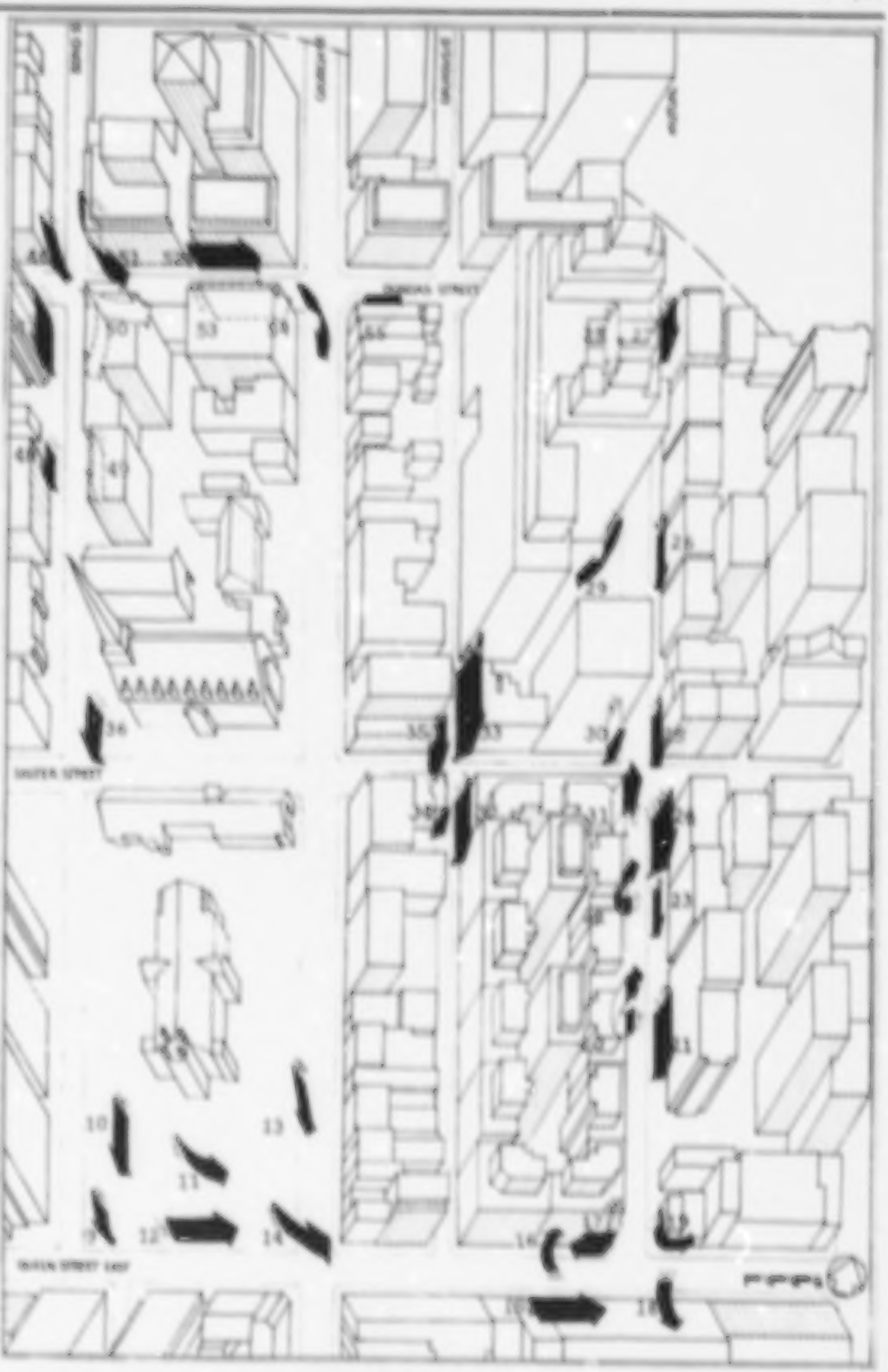
East Downtown, Potential Conditions, Northwest Wind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East Downtown, Mitigated Conditions, Northward Wind

Comfort in the Spring

Existing Conditions

Under the existing conditions, approximately half of the points tested are too cold to be comfortable in the spring. Most of these are on the north side of tall buildings where sunlight is blocked or on the south side of east-west streets, where the sun rarely reaches. The area set aside for the proposed Dundas Square (not shown on the map) is moderately comfortable and most of the park in front of the Metropolitan United Church is very comfortable.

Potential Development

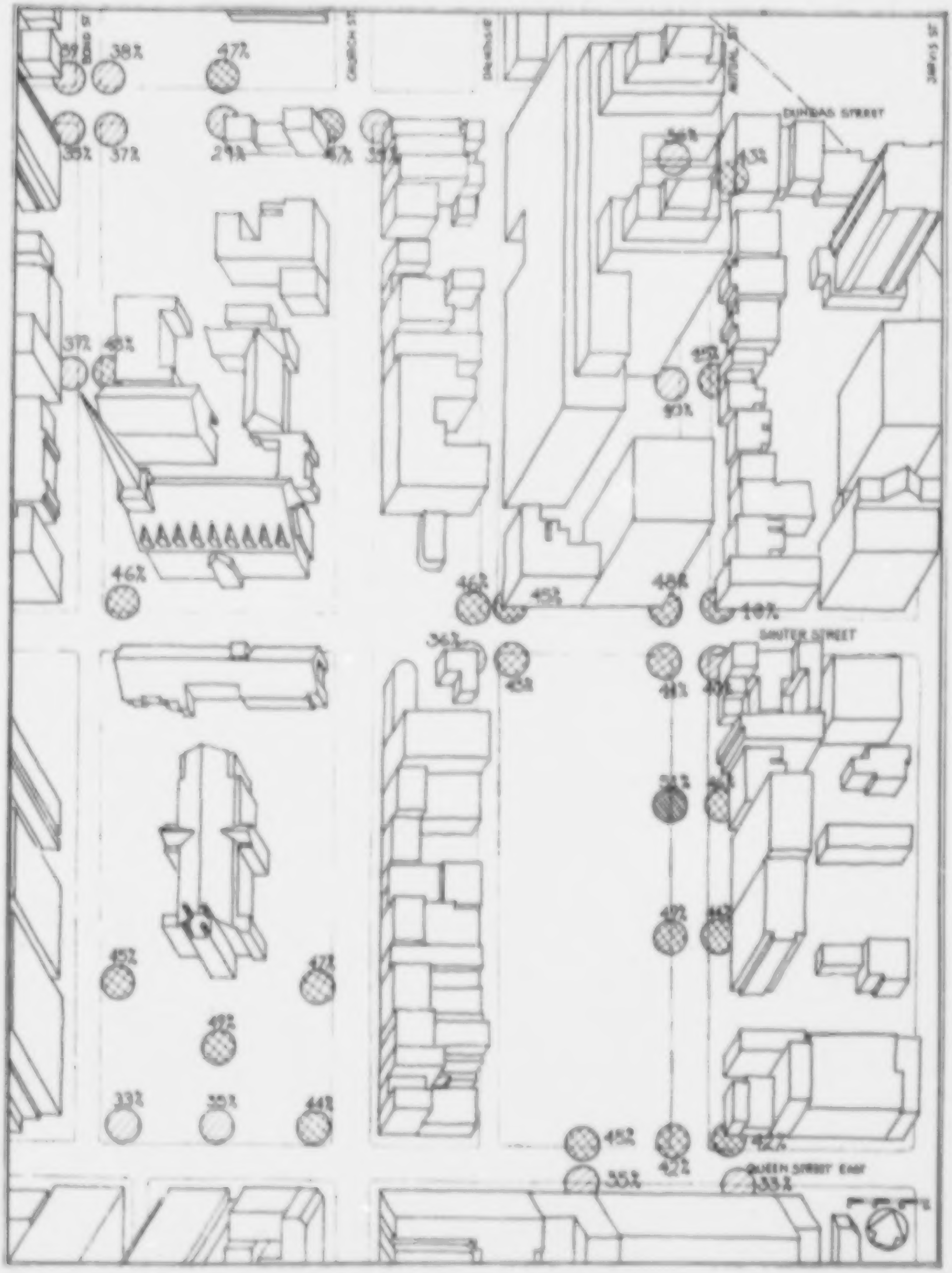
Under the potential development scenario, approximately two-thirds of the points tested are too cold to be comfortable. There is a particularly dramatic change at the corner of Mutual and Shuter, which was comfortable most of the time under the existing conditions. The change here is due to the combined effect of the higher winds and increased shading from the new buildings to the south.

Mitigated Development

In the mitigated development scenario, more points would be comfortable than under the existing conditions. Both Mutual Street and Shuter would receive sunlight for five hours during midday, and the development possible at the Cookes Church Block would have significantly fewer adverse impacts from both shadow and wind. Points along Dundas Street (three hours of sunlight during midday), are more sunny and, hence, more comfortable than in the potential scenario showing an increase in comfortable hours of 5 to 10 percent.

Comfort Scale

25%-41%	42%-51%	52%-60%
▨	▩	●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MUTUAL ST
JARVIS ST
DUNDAS STREET
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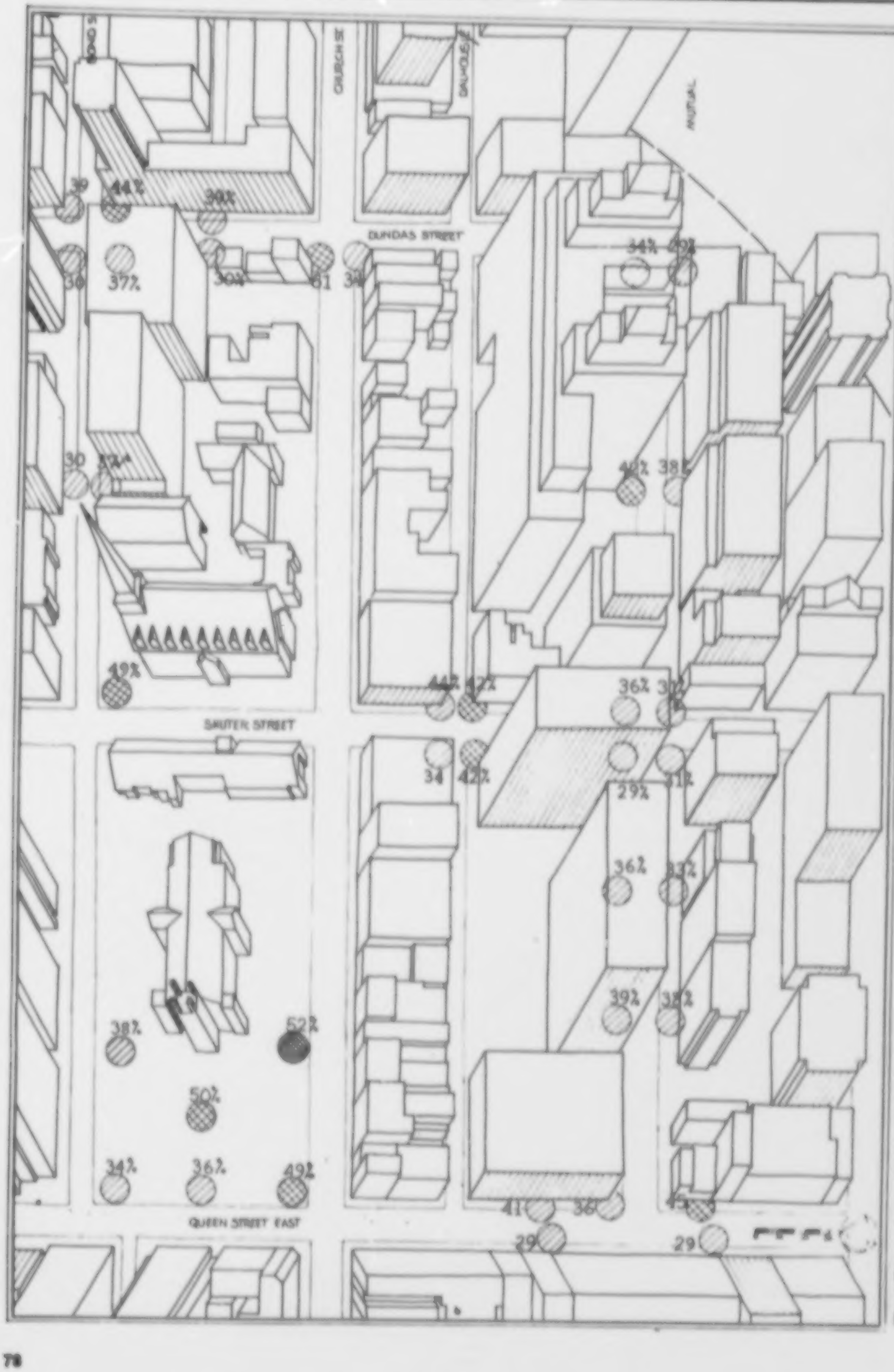
QUEEN STREET EAST
33%

East Downtown, Existing Condition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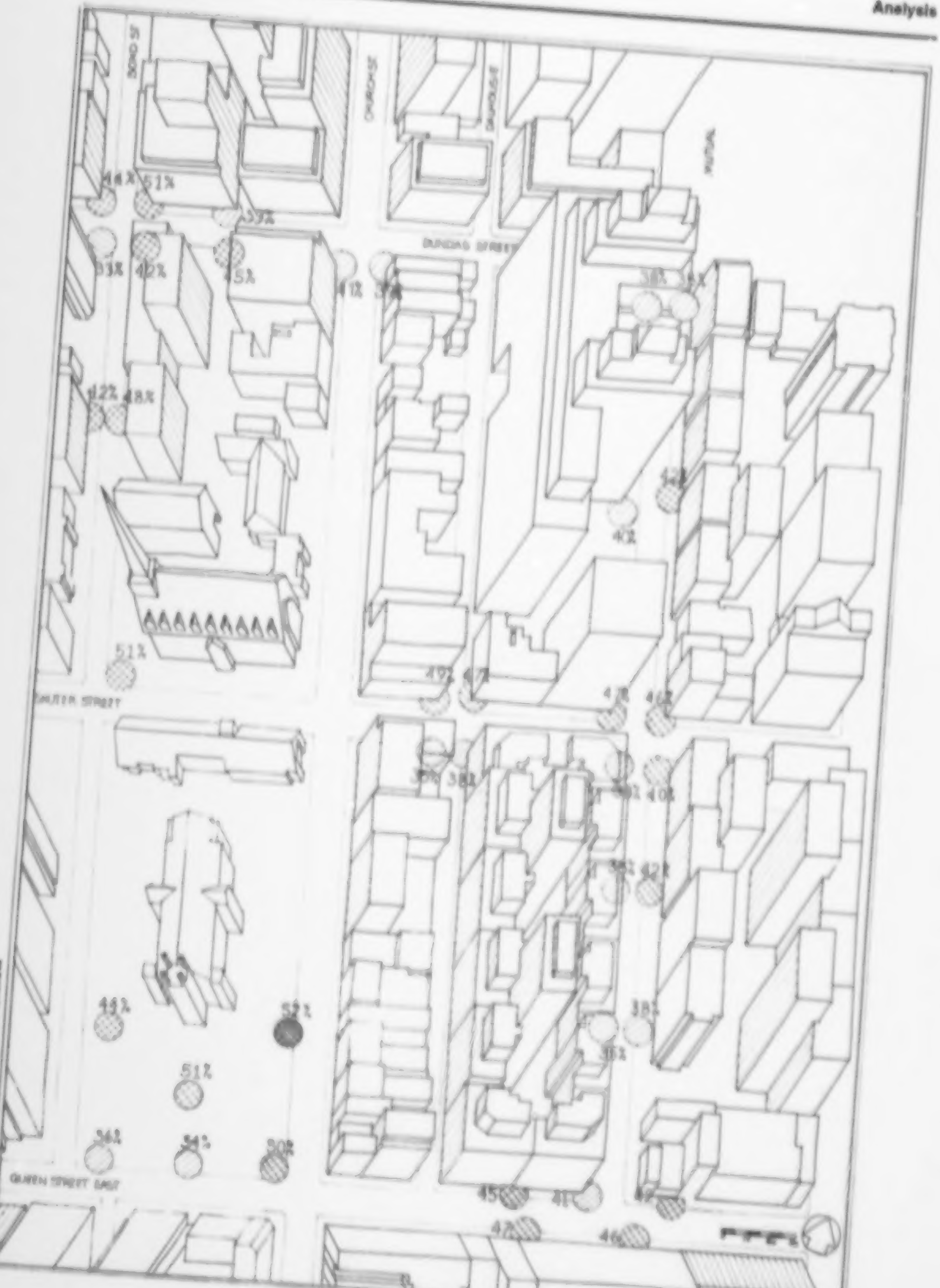
East Downtown, Potential Conditions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East Downtown, Existing Condition

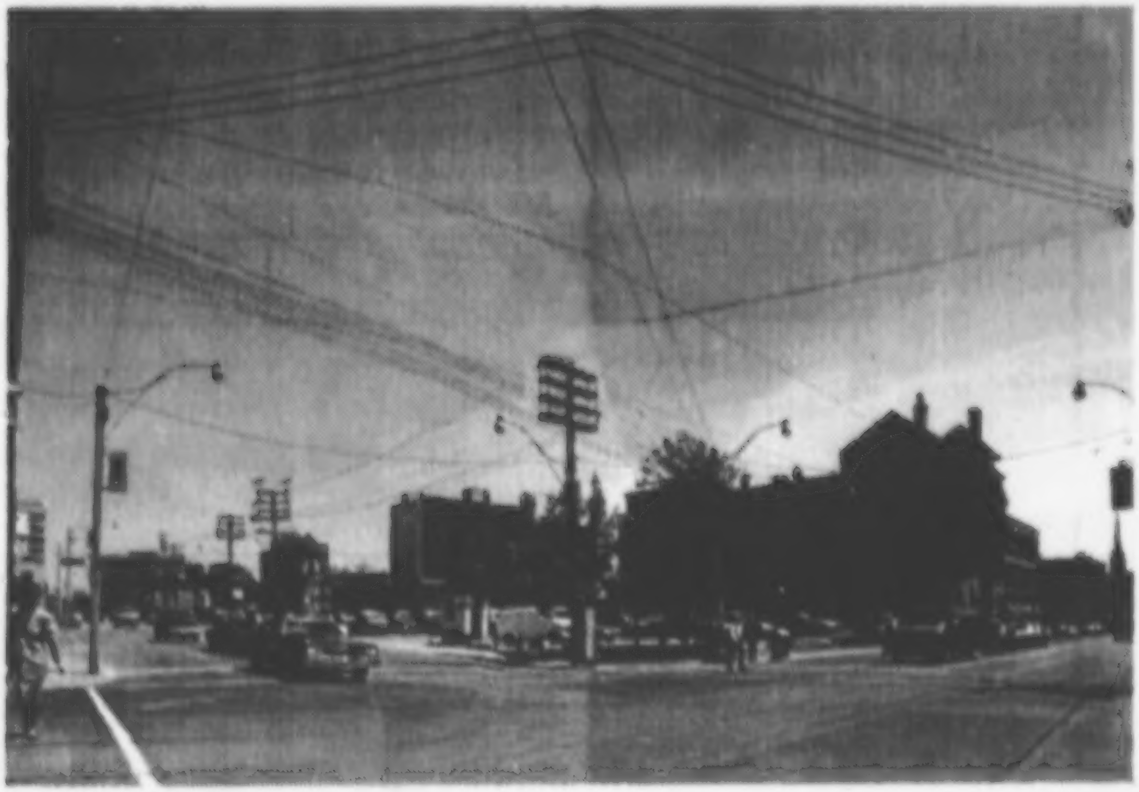


Fig. 4.5a Shuter and Church Streets
Existing Condition

Built Form

The computer simulations shown in Figs. 4.5a, b, and c show the intersection of Shuter and Church Streets looking west on Shuter Street. Under current planning controls, a low-rise development is possible on the northern portion of the block between Shuter, Church, and Dalhousie Streets.

The development of this site under the mitigated scenario would allow four or five floors or 14m of building height along the property line on the south side of Shuter Street. The development facing Church Street could go up to the height limit of 18m or 6 floors. The sun access plane providing three hours of sunlight to the western sidewalk of Church Street is not limiting building heights on this site. It would have allowed a streetwall of 31m, well in excess of the 18m height limit. A five-hour standard (not considered in the modeling experiment for Church Street, but later considered in the recommendations) would limit the streetwall height to 16m, or 5 to 6 floors. The building in the middle ground on Church Street is listed as a historic structure. Its height would be within the five-hour standard. Along Shuter Street, in the middle ground, the development of the Shuter, Mutual, Queen, and Dalhousie block is visible (referred to as Cookes Church Block). This development is shown here from the north, with a tall, 46m-high tower along Shuter Street. Under the mitigated scenario this development would be significantly lower. It would follow the same streetwall height of 14m as the building in the center of the picture.

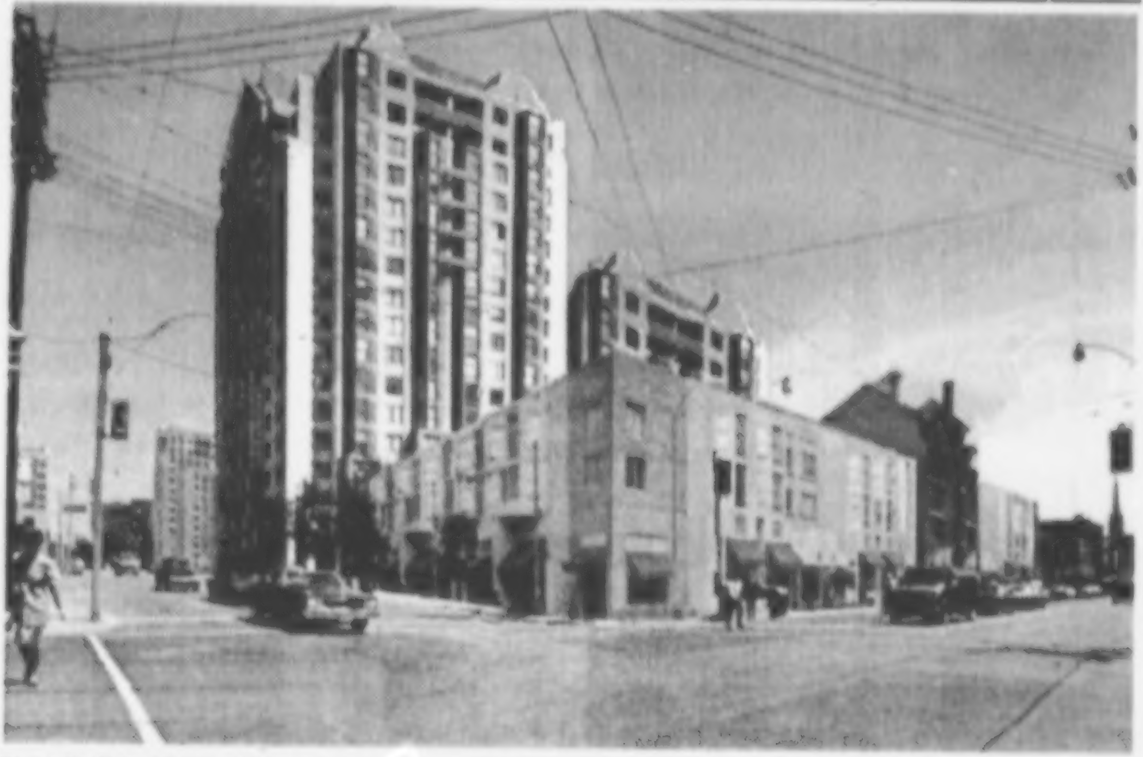


Fig. 4.5b Potential Condition

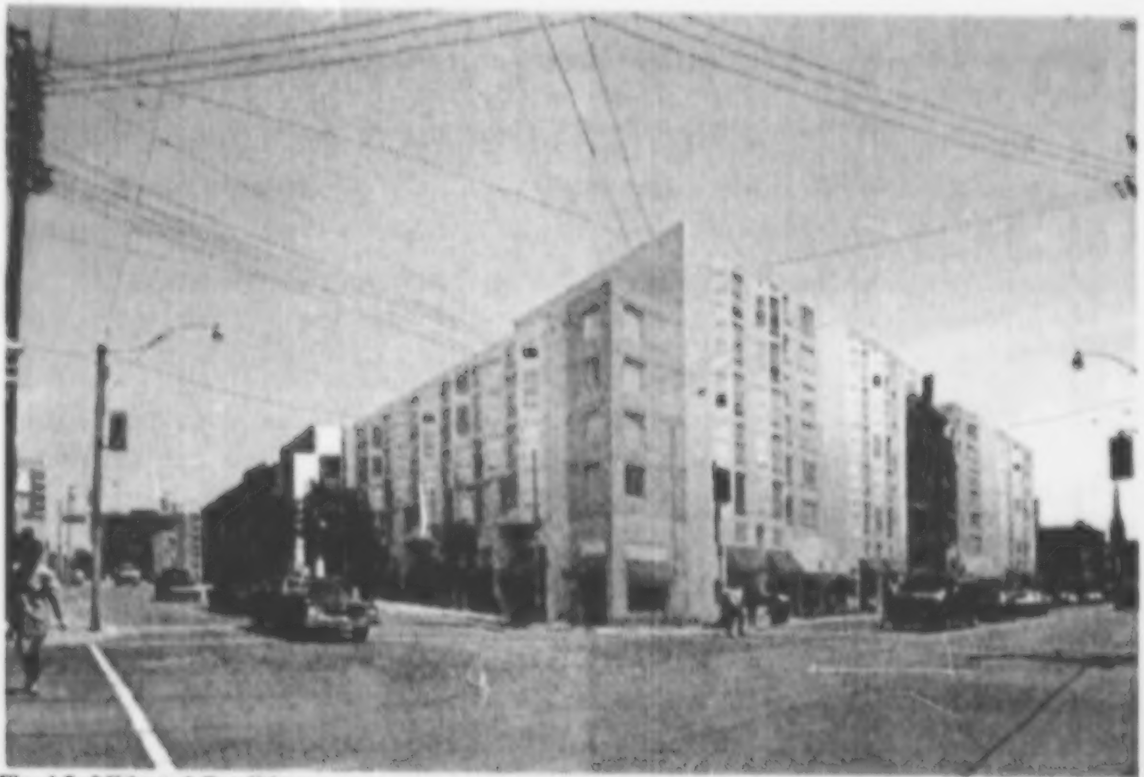


Fig. 4.5c Mitigated Condition

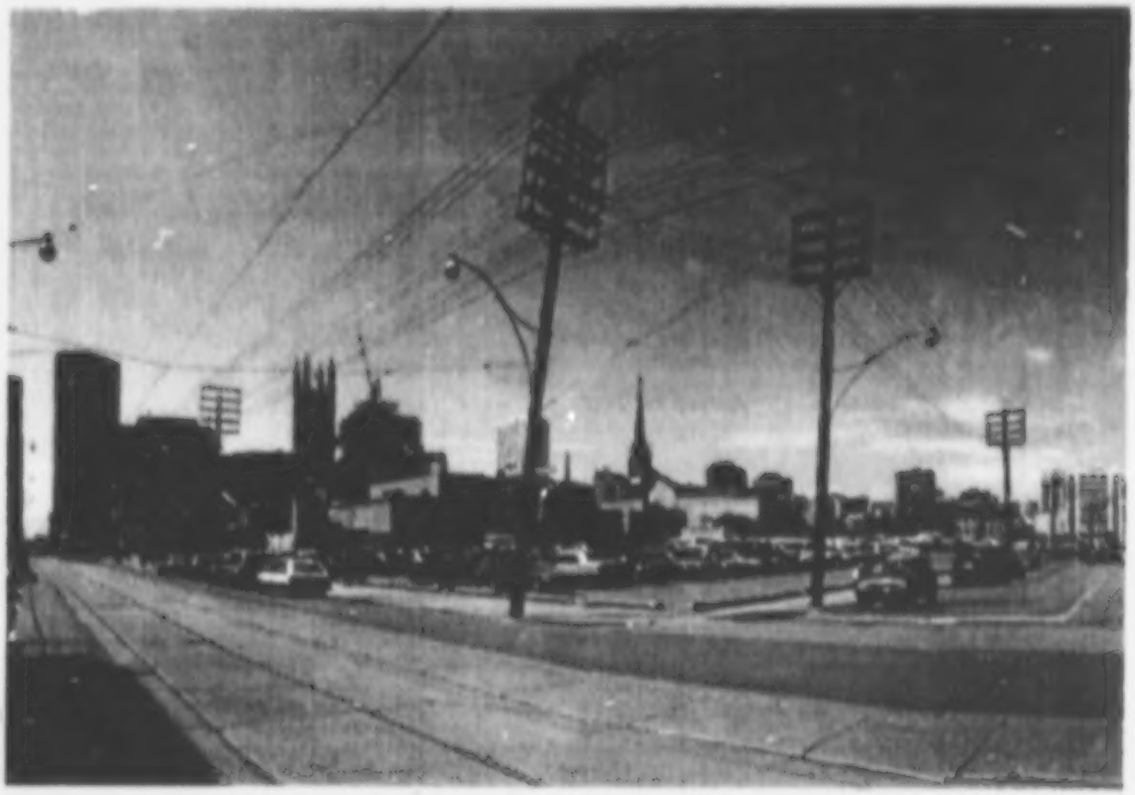


**Fig. 4.6a Queen and Mutual Streets
Existing Condition**

The Cookes Church Block is shown again from the intersection of Queen and Mutual Streets.

Potential Development

Under the Potential development, this block would have a low-rise, non-residential structure along Queen Street. Along Mutual Street, a 47.5m high tower would be constructed and a similar tower along Shuter Street shown in Fig. 4.5.

Mitigated Development

The same density was achieved in the modeling of the mitigated scenario. Along Queen Street, the streetwall height would measure 16m. This height would also limit buildings along Mutual Street, but additional floors for apartments could be constructed under the five-hour sun access plane of 44 degrees. Along Dalhousie Street (not visible in the picture), a three-hour sun access plane was applied. Although Dalhousie Street is narrow, the greater angle of the three-hour plane (60 degrees) permits a highter streetwall of 20m, and--given the steep 60 degree angle--the zoning height limit of 46m can be reached. (The height limit could not be reached along Mutual Street under the lower 44 degree angle. In the recommendation section, Dalhousie Street was reclassified as a five-hour street, resulting in a maximum allowable building height of 30m).

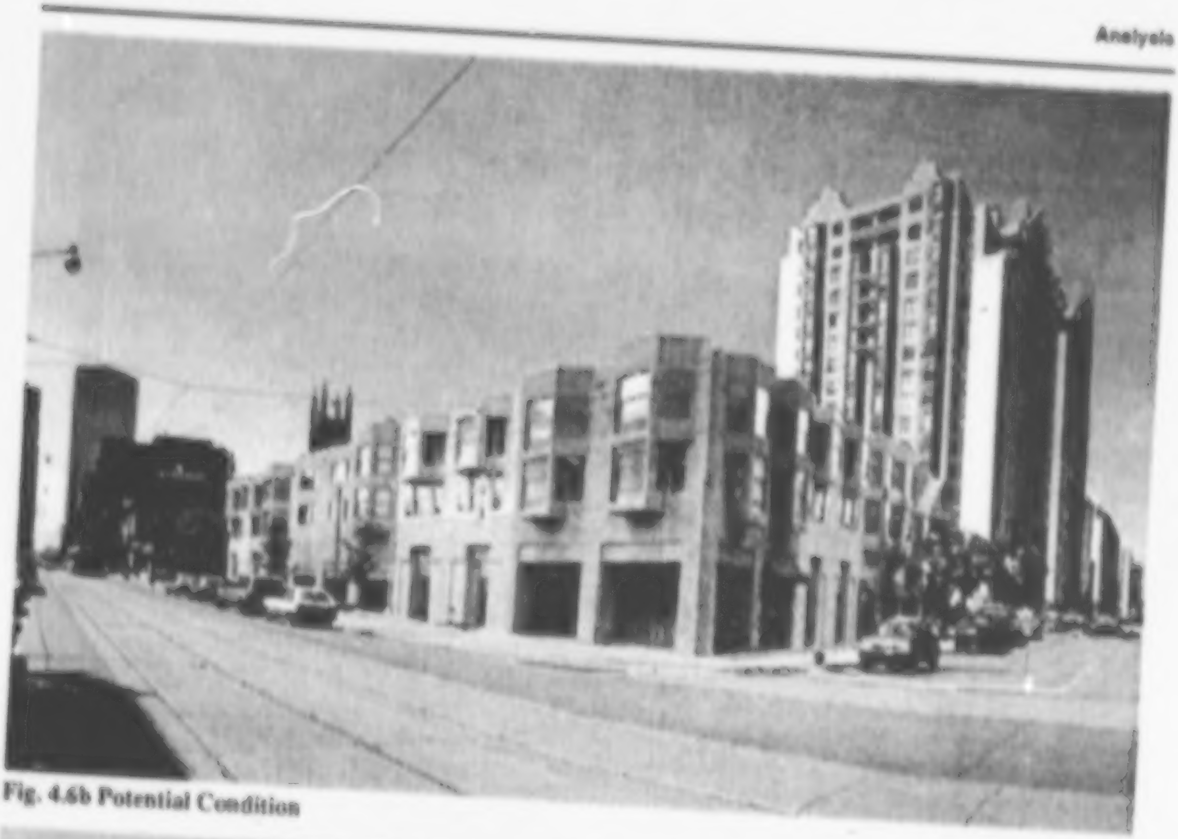


Fig. 4.6b Potential Condition

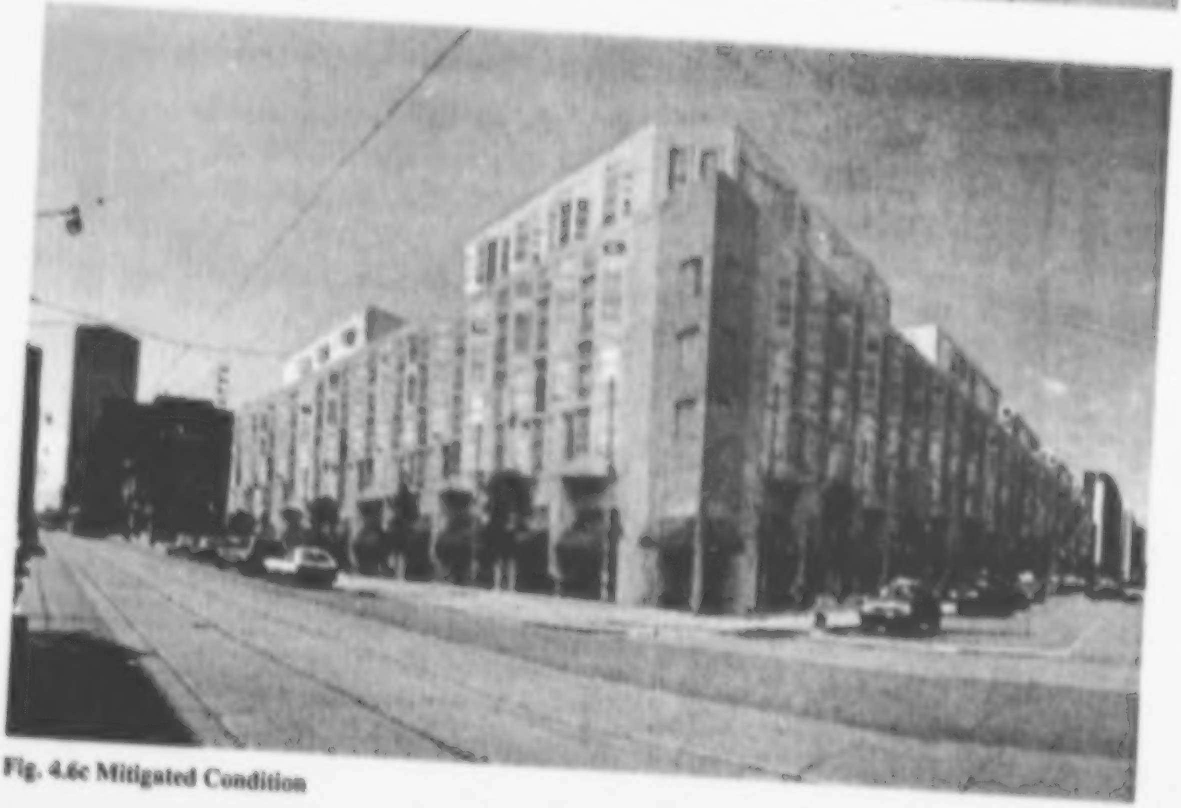


Fig. 4.6c Mitigated Condition

4.2.3 Railway Lands / Lakefront Area

Wind

Existing Condition

Under the existing conditions, the wind measurements vary according to the surroundings. Wind ratios measured in the undeveloped Railway Lands are generally high when the wind is coming from the northwest and is unobstructed. Ratios are 0.65 to 0.80, below the threshold considered uncomfortable for people walking. The east wind produces even higher ratios, but the west and southwest winds produce the highest ratios -- ranging from 0.85 and 0.95. Along Queens Quay the winds are comfortable where buildings are low. Only at the end of Bay and York Streets would one experience uncomfortably forceful winds. Along the water, most places are very windy, especially next to the tall buildings because of the strong winds produced at building corners. The park at the Bay Street slip has the highest ratios for this area (1.17), because the wind is accelerated in the gap between the two towers on days when the wind blows from the northwest.

Potential Development

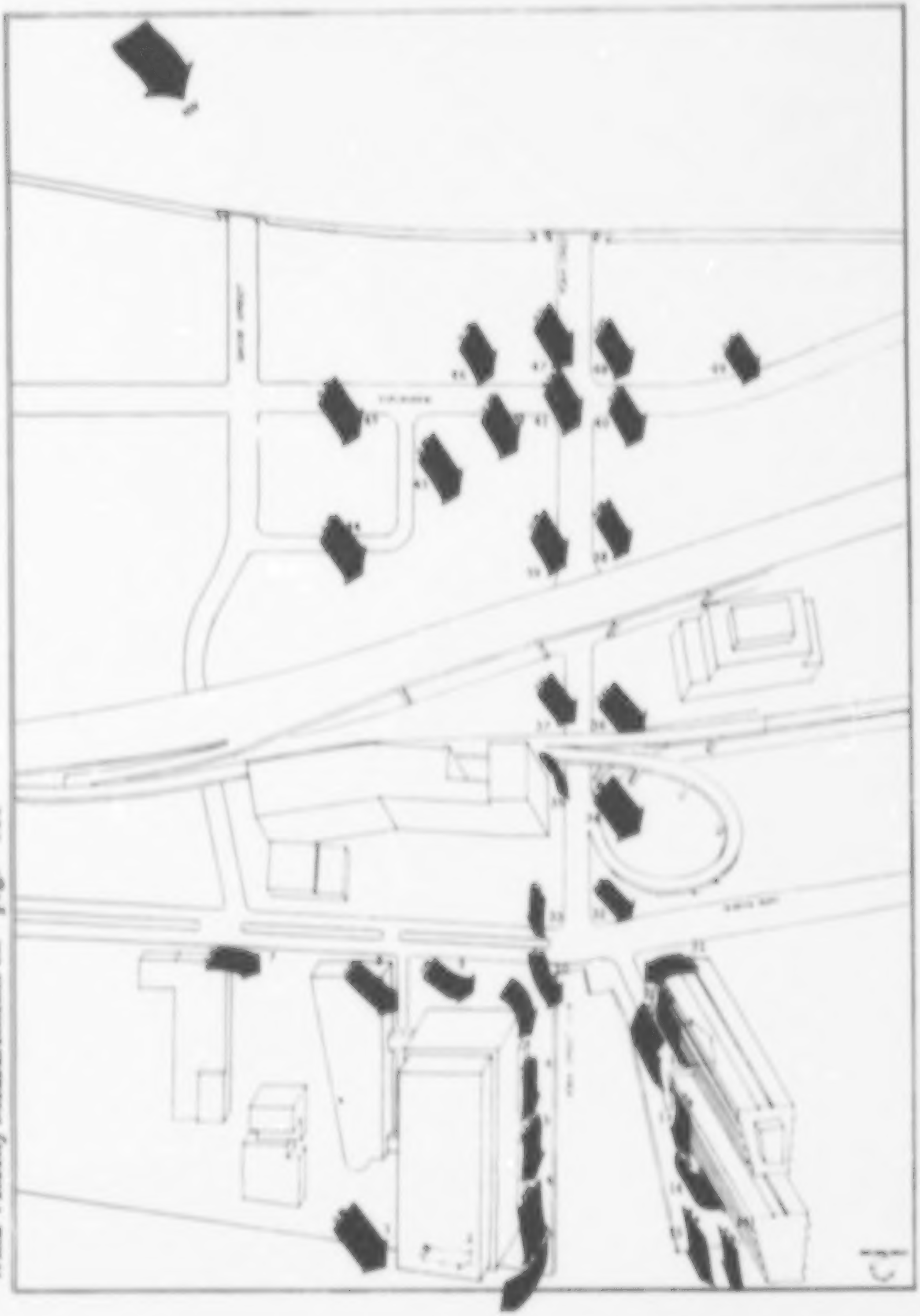
In the potential development scenario under the 1985 Plan, the combined effect of the many new towers would result in very severe winds along the proposed Esplanade near the corner of York Street. Wind coming from the west or northwest meets this group of towers abruptly and is channeled around and down into the streets rather than passing over. Almost every point measured showed a ratio of 0.8 or greater which would be uncomfortably strong. Many of the ratios were above 1.1, meaning that walking would be impaired some of the time. When the wind is from the east, this area is more sheltered by the existing and potential towers, and the winds would not be as strong. On the waterfront, the northwest wind produces lower wind ratios than the existing condition because the new development upwind acts as a barrier and shelters this area. When the wind comes from the northwest, west, and southwest directions, this sheltering does not occur and the ratios are very high.

Mitigated Development

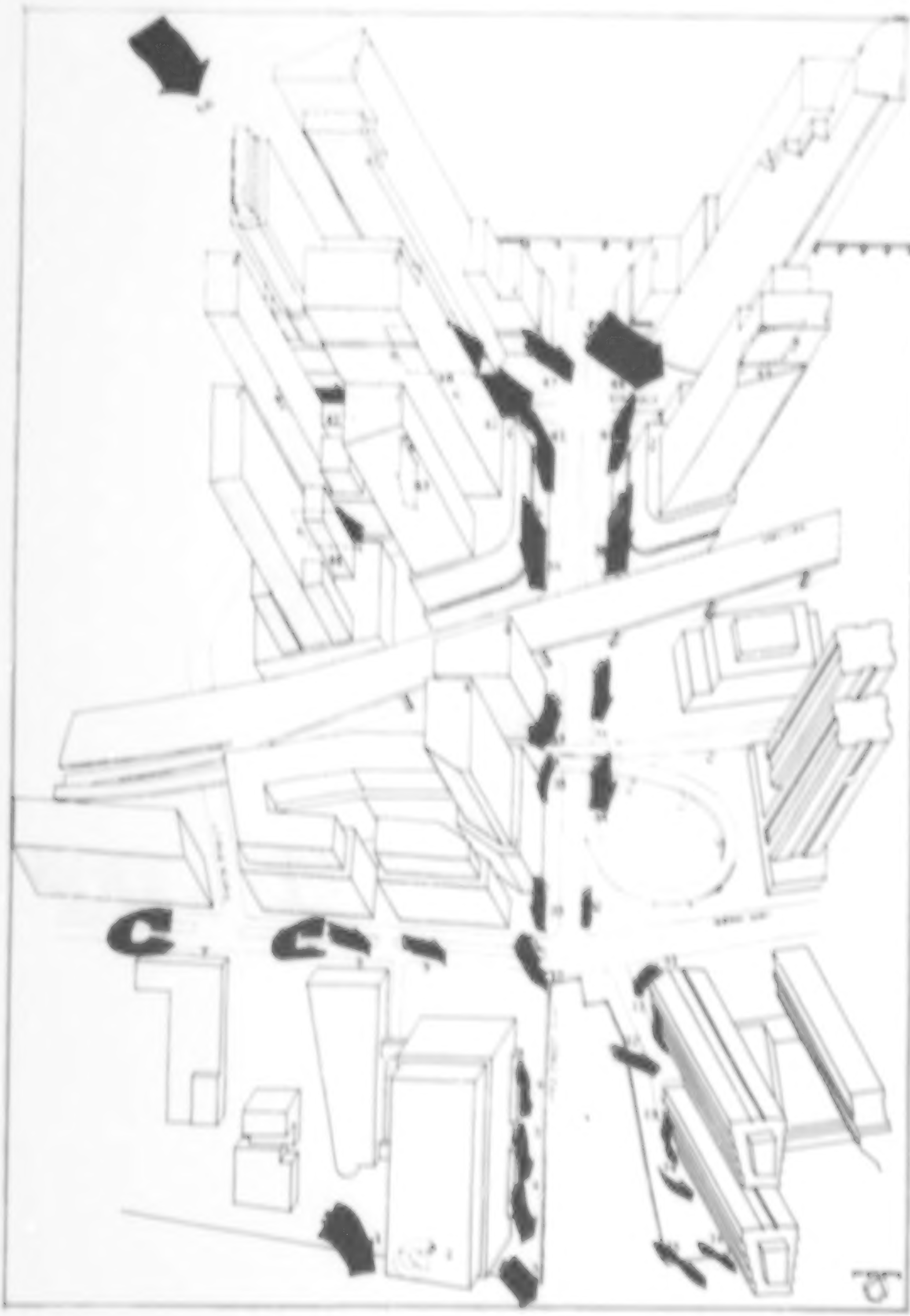
With the development possible under the mitigated scenario wind ratios measured amid the development on the Railway Lands would be reduced significantly -- by 20 percent to 50 percent. However, along the Esplanade and along York Street the wind velocity ratio still reaches 0.8 in a number of places under northwest, west, and southwest conditions. Smoke visualization clearly showed how the tower setbacks above the streetwall height help to reduce the downwind effect created by towers. But the base portions of buildings possible under mitigated development (with street wall heights of 30m to 42m high) create wind velocities that are still very high. These velocities would be in conflict with a standard that prohibits winds in excess of 18 km/hr in areas where people walk. In order to reduce the wind velocities at sidewalk level, a reduction of the streetwall heights would be beneficial and would reduce the channeling of the wind along the Esplanade, York Street, and along a new street in line with the view axis between the Royal York Hotel and Harbour Square. Also, a reduction of the width between street walls from, currently, 40m along York Street and 36 m along the Esplanade would provide shelter from the westerly wind.

In the mitigated development scenario, the points along the waterfront remain as sheltered from the westerly wind as they were in the potential development scenario, but are uncomfortably high when the wind approaches unobstructed from the east, across the lake.

Wind Velocity Measurements on page 101

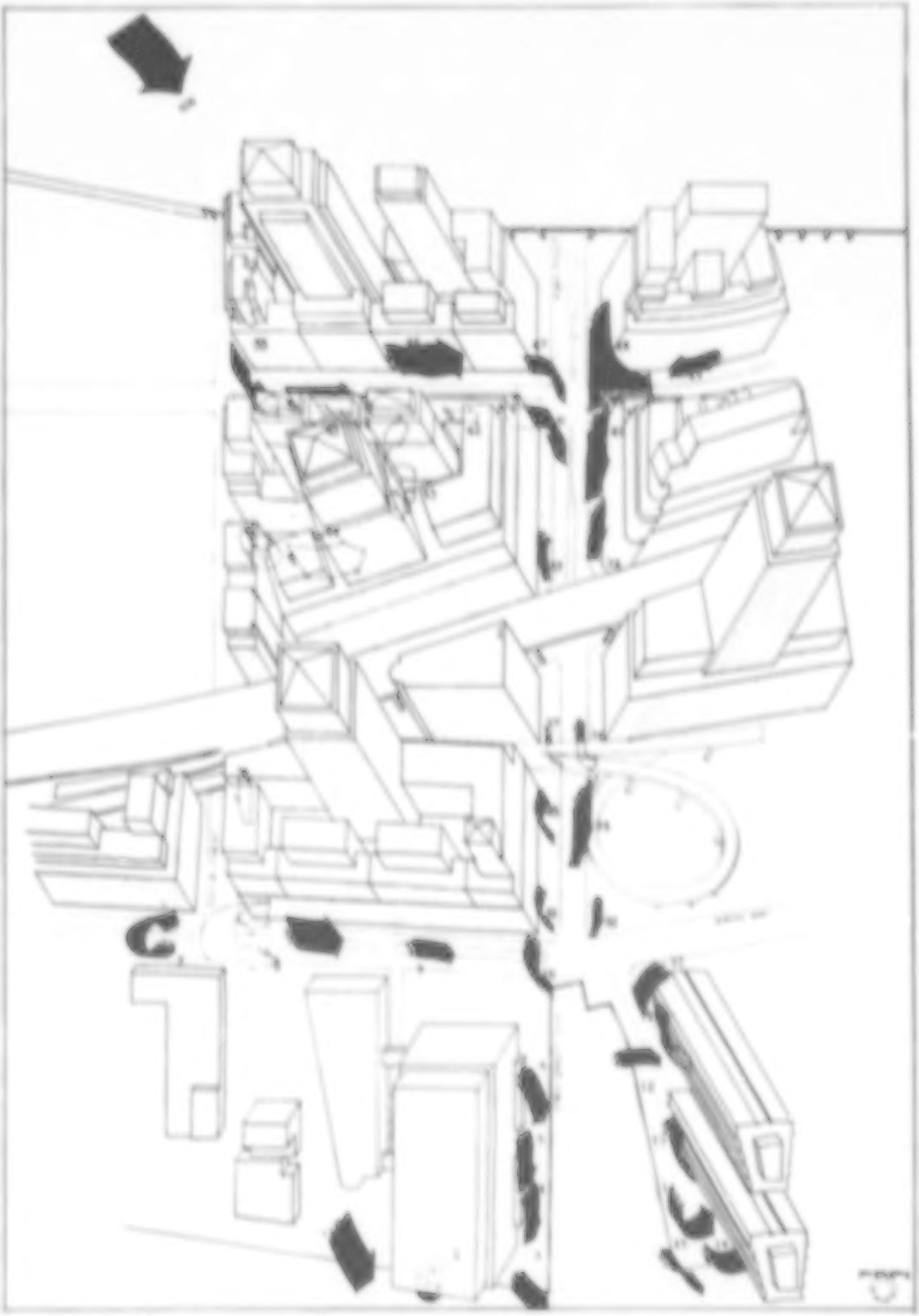


Railway Lands, Existing Condition



Wind Velocity Measurements on page 101

Railway Lands, Potential Condition



Wind Velocity Measurements on page 101

Railway Lands, Mitigated Condition

Comfort in the Spring

Existing Condition

Under the existing conditions, most of the points tested in the developed part of this area are uncomfortably cold most of the time. This is due to the shadows cast by the towers on the waterfront and the high wind ratios next to most of the towers. The undeveloped lands are moderately comfortable because they are in sunlight almost all day.

Comfort Scale

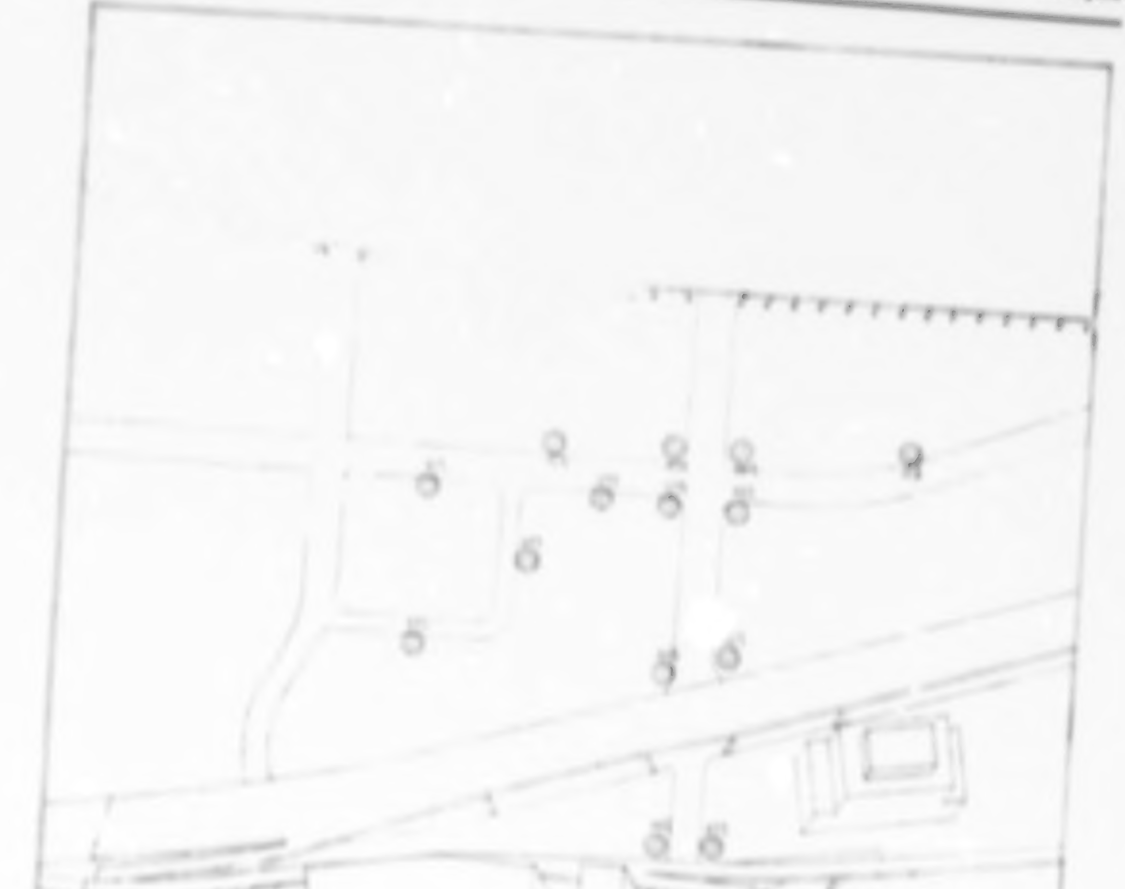
25%-41%	42%-51%	52%-60%
▨	▩	●

Potential Development

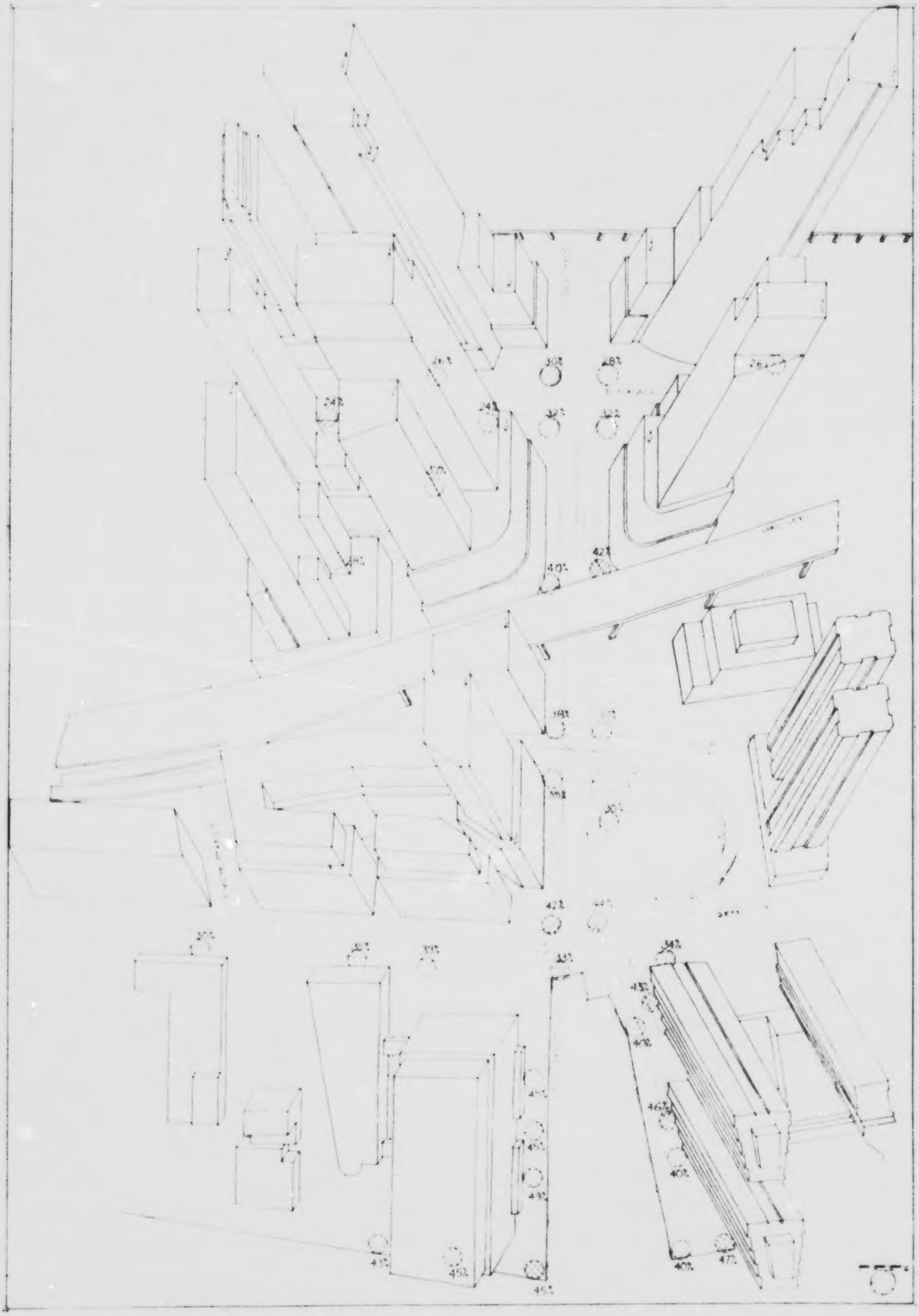
When potential development is modeled, all of the points within the newly developed Railway Lands are uncomfortably cold most of the time, because the streets and sidewalks are shadowed almost all day and high wind ratios are common. The points along the waterfront are slightly more comfortable than under existing conditions because this area is now sheltered from the northwest and west wind.

Mitigated Development

In the mitigated development scenario, many of the points along the Esplanade would be moderately comfortable because of the combination of increased sun access and decreased winds. York Street would be generally comfortable, and the waterfront would be more comfortable than under the existing conditions.



Railway Lands, Existing Condition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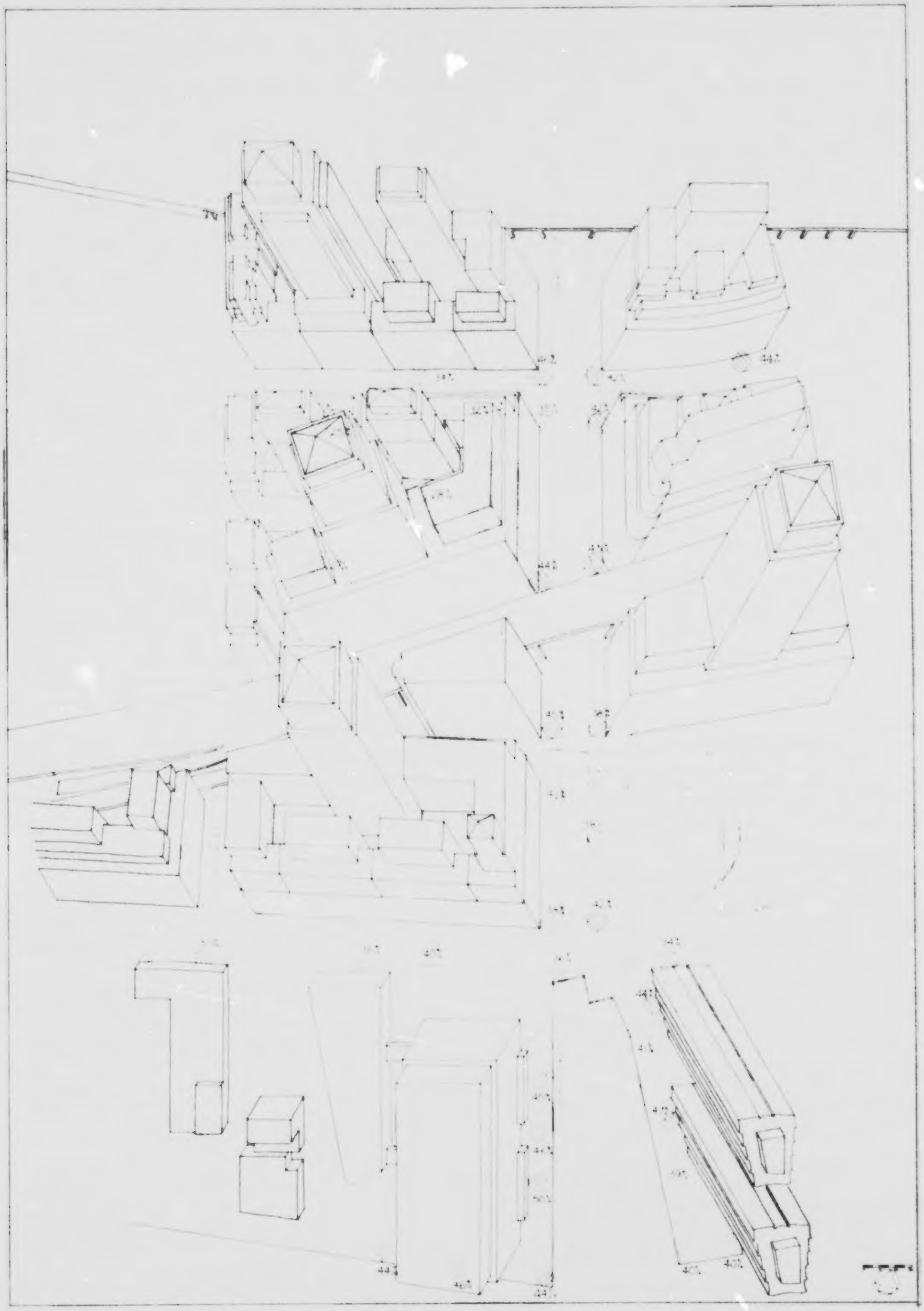
Railway Lands, Potential Condition



Railway Lands, Potential Condition

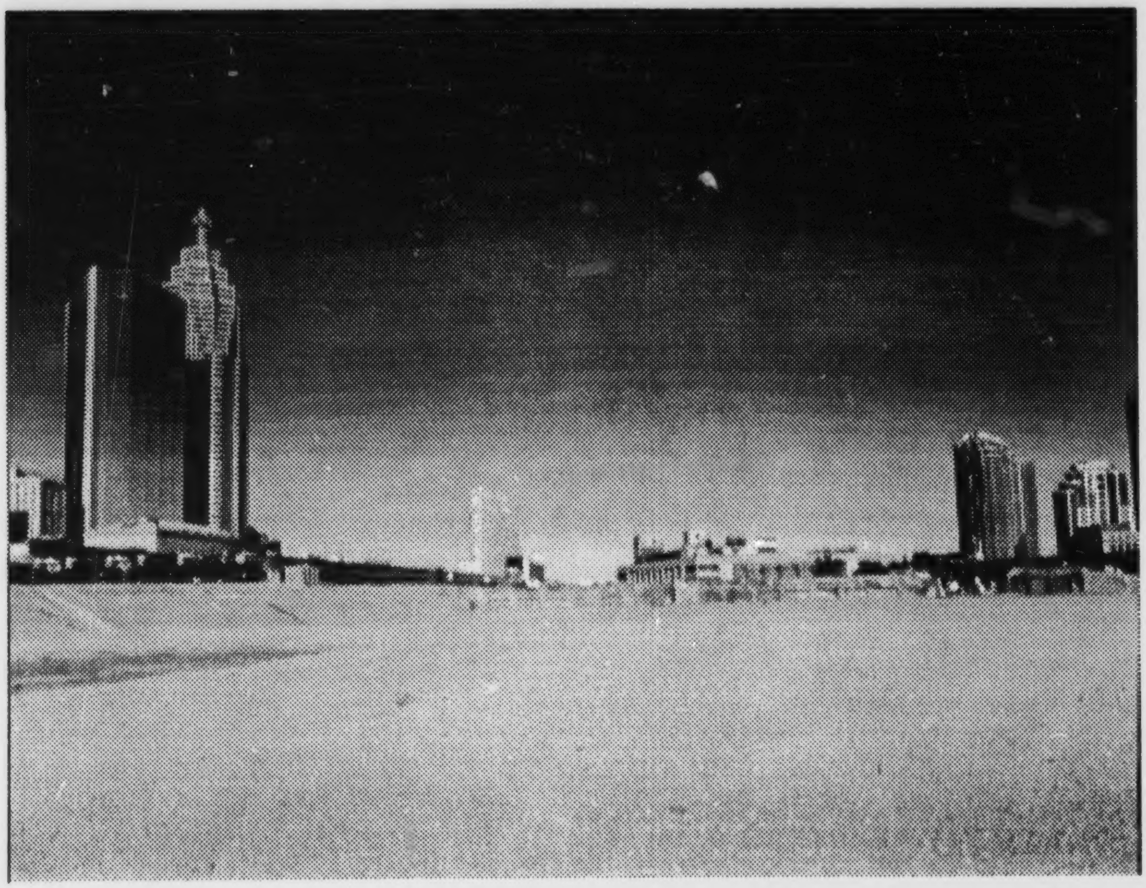


Fig. 4.8.a Existing Condition

Built Form

The eye-level simulation shows a future view pedestrians would have crossing the new Esplanade along the future alignment of Simcoe Street near the proposed Roundhouse Park.

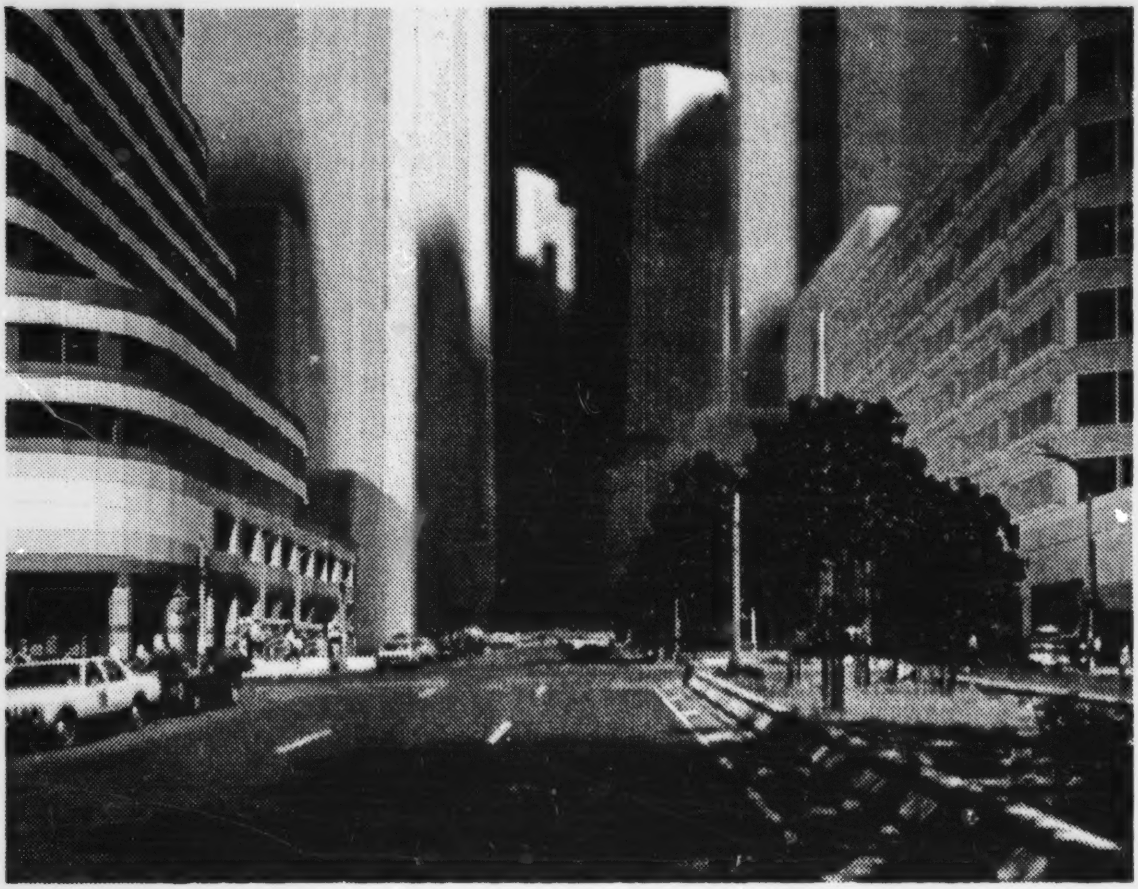


Fig. 4.8.b Potential Development

Fig. 4.8b shows the future view of the 36m-wide Esplanade at Simcoe Street. The Esplanade is lined with builings possible under the Potential Development Scenario. The height of these buildings goes well beyond the upper frame of the picture. The buildings would be as high as 176m on the south side of the Esplanade, and 137m or 195m on the north side. In a distance, the Esplanade curves toward the north and is reduced in width near the intersection with Bay Street.

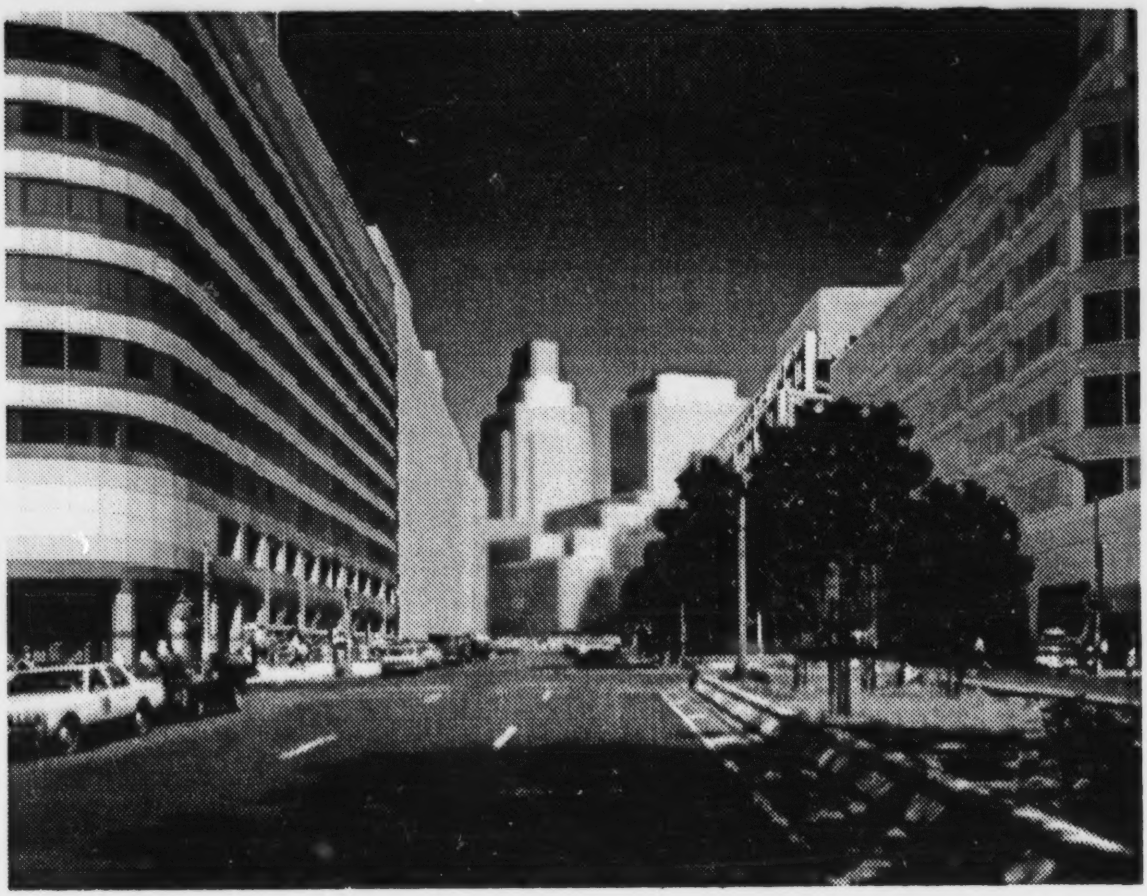


Fig. 4.8.c Mitigated Development

Fig. 4.8c shows future buildings under mitigated development. The mitigated building volumes would provide sunlight for the northern sidewalk of the Esplanade from 12:18 D.S.T. (or 11:18) on the spring and fall equinox. York Street intersects with the Esplanade in the middle ground. The York Street sidewalks would receive three hours of sunlight during midday at the same time of year. The development on the south side of the Esplanade has a street wall height of 24m.. A sun access plane sloping at an angle of 44 degrees defines the height of three towers located in this block to the south of the Esplanade. To the north of the Esplanade, the streetwall height measures 30m. Tower buildings step back by 20m above the 30m street wall, at which point a tower with a maximum plan dimension of 45m x 55m can be built up to a height of 137m, the established height limit. None of the towers to the south or to the north in the first block between Simcoe and York are visible on these simulations of the mitigated development.

5. FINDINGS AND CONCLUSIONS

Comfort conditions during the spring and fall would improve if buildings designed under mitigated development controls were built.

In most cases, the mitigated development would also produce better comfort conditions and wind protection in the winter. The year round wind conditions on sidewalks and in open spaces would improve. However, several locations would still measure equivalent windspeed ratios in excess of 0.8. Here, building volumes would need to be further modified to mitigate against certain wind effects. In some cases, such as along Bloor Street, the wind conditions induced by existing development are such that almost no future development could affect or correct these conditions. These locations are the intersection of Bloor and Bay and Bloor and Yonge Streets.

While this study focused on three areas in Toronto and produced area specific findings, some broader generalizations can be made. A wide range of wind and comfort conditions was found in the streets and open spaces evaluated in this study. The highest wind ratios were found at street corners near large high-rise buildings that are exposed to the prevailing wind directions. The calmest conditions were found along streets of uniform low building heights. Generally, winds in parks and other open spaces were considerably more calm than winds along streets. Overall, the wind velocities in the Yorkville area north of Bloor Street were the lowest of any area in the study. This area is sheltered from east and southwest wind by high buildings along Bloor and Bay Streets. The homogeneous building heights to the north create a wind environment that is calm for winds from the northwest and north. Existing height limits protect this district from development conditions that would produce adverse wind velocities.

Similarly protected from strong winds are streets in East Downtown. However, in this area, high buildings possible under current planning controls would produce windier streets and would produce sections of sidewalks that are less comfortable.

Few sections of streets with generally calm winds are found near the Lakefront and in the section of the Railway Lands properties between Union Station and the Gardiner Expressway. Similar to conditions along Bloor near Bay and Yonge, this part of Toronto has very strong wind velocities. Existing wind velocities along York and Bay Streets would increase if buildings proposed along these streets were constructed on the Railway Lands properties.

Wind in Streets

Within all three study areas, locations are found where winds produce uncomfortable conditions. As mentioned earlier, wind velocities of 18 km/hr (11 mph) are generally considered uncomfortable for people walking on sidewalks. Equivalent wind speed ratios of 0.8 will be uncomfortable, if a 22 km/hr ambient windspeed is measured at a weather station. Windspeeds of 22 km/hr and greater occur in Toronto, particularly on days with west winds during the winter months and on days with winds coming out of the northeast and east in the winter and spring.

Points with wind velocity ratios above

0.8 are found throughout all three study areas, in the Railway Lands, in the Lakefront Area and along Queens Quay and near York Street Quay. In the East Downtown area, equivalent windspeeds of 0.8 and greater are found near the intersection of Shuter Street and Dalhousie and on Dundas between Bond and Church Streets. Along Bloor Street the equivalent windspeed exceeds 0.8 at many points, especially near the intersections with Bay and Yonge.

Winds in Parks

In open spaces, wind speeds of 11 km/hr are considered uncomfortable for people sitting on benches. Here an equivalent windspeed ratio of 0.6 would be considered unacceptable at those times when the weather station windspeed exceeds 19 km/hr. Weather station wind velocities of 19 km/hr and higher are frequently measuring during all seasons of the year. In our three study areas, we measured windspeeds in excess of 0.6 at Cumberland Park at the site of the potential Dundas Square, at the Metropolitan Church, and along the harbourfront boardwalk.

Comfort Findings

One of the study's most basic findings was that under Toronto's climatic conditions, sunlight in the spring and fall will produce comfortable conditions for pedestrians. Direct sunlight during the summer will generally result in conditions that are too hot to be comfortable, and people frequently seek shade and a light breeze to stay cool. During the winter, pedestrians in warm clothing and those that are active will be comfortable in direct sunlight at midday, but only when the location is sheltered from the wind.

Between the hours of 8 a.m. and 7 p.m. during the spring and fall, most sunny locations in Toronto are comfortable from 38 to 54 percent of the time. Locations in the shade during that time period are rarely comfortable more than 35 percent of the time. On typical days in January between the hours of 9 a.m. and 5 p.m., locations in the sun are comfortable up to 47 percent of the time for a persons warmly dressed (clo 2.5) and actively walking.

The study analysis found that existing comfort conditions vary considerably from area to area. Yorkville has the best comfort conditions of all areas studied. Even in the winter, Yorkville Avenue is comfortable 44 percent of the time for a person dressed in warm winter clothing and walking at a clipped pace. In the spring and fall, for a person more lightly dressed, a leisurely stroll along Yorkville Avenue is comfortable 45 to 54 percent of the time. Again, the reasons for these conditions are the low building height, ample sunlight, and protection from the wind.

On Bloor Street, two blocks to the south, conditions in the spring will be comfortable only 25 percent to 37 percent of the time. Most of the time, Bloor Street will be too cold in the spring for the casually strolling pedestrian. But the conditions will be somewhat more comfortable in the fall. The East Downtown conditions are generally comfortable in the spring and very comfortable in the fall.

In the area near the Lakefront and along York Street, existing conditions are generally comfortable in the spring and fall, except at locations where existing high buildings produce strong winds at the street corners.

Built Form

The modeling of the two hypothetical development scenarios has allowed us to compare future development under current planning controls with development that might be built, if revised planning controls were legislated. It is important to keep in mind that our modeling is the result of an experiment made under controlled conditions.

Assumptions were made in the modeling to ensure the validity of the comparison between the two development scenarios. These assumptions, however, can be questioned when we consider predictions of a future reality. Before we proceed with a discussion on the effects of comfort controls on built form, we need to review the assumptions that were made in the modeling of the mitigated scenarios. These assumptions were explained in detail in the methodology section of this report:

Assumptions Made in the Modeling

The objective of the modeling was to demonstrate that it is possible to mitigate the effect built form has on the microclimate of streets by modifying the placement, height, and bulk of future development. For this purpose we constructed building envelopes that met the objectives of mitigation measures. These measures include sun access criteria and considerations for the placing of buildings that are indented to reduce strong surface winds.

Three assumptions guided us in the modeling of this mitigated scenario:

Density and Lot Assembly

We assumed that the same amount of floorspace (coverage) would be built under current planning controls as under comfort controls. If we had not made this assumption, and simply lowered the coverage under the mitigated scenario, improved comfort conditions could have been attributed to a lower coverage and not to the mitigation measures. While it is likely that future development would be built to the floor area limits set by a current or future Official Plan, there is no guarantee that sponsors of future projects would indeed develop the same amount of floorspace under existing planning controls as they would under comfort controls.

Hidden in this assumption on equal density is the notion of land assembly. Many of the larger sites that were chosen for modeling under current planning controls had been, or could be assembled. The question is, would land assembled for development under current planning controls also be assembled for development under comfort controls? Any answer will remain speculative. The comfort controls might discourage lot assembly because the built form that would result might not be as economically feasible as separate developments on smaller lots over time. The contrary could also be argued. Comfort controls might encourage assembly of parcels because development on a larger zoning lot might not be as constrained by sun access and wind controls. Other reasons exist that influence decisions regarding the assembly of land. Given the speculative nature of this question, we decided that our modeling could only be consistent if we assume future development on identical lot configurations

Building Heights

In the modeling of the mitigated scenario, we applied sun access planes that preserve sunlight on sidewalks for three or five hours encompassing the midday period. We assumed that buildings under the mitigated scenario would be built up to these sun access planes, but that the zoning height limits would remain in force above those portions of properties that are unaffected by the sun access standards. This assumption allows us to compare building configurations of similar height under the potential scenario with buildings under the mitigated scenario. While it is likely that buildings will be built up to height limits, in the Central Area of Toronto where land values are at a premium, there is no guarantee, however, that this will be the case with all developments.

"Build-to" Line

Finally, we assumed that development under the mitigated scenario would follow a "build-to" line. Such a "build-to" line would require buildings to be built along the perimeter of city blocks at the property line or at a line that runs parallel to the property line. If buildings follow such a line, a continuous streetwall will result. A street wall provides shelter from the wind and therefore contributes to a better microclimate at street level. In some cases, "build-to" lines have been used in Toronto; they are part of urban design plans for specific areas. In general, however, "build-to" lines are currently not used for all properties in the Central Area.

These three assumptions have guided the modeling of the mitigated scenario; they have affected the form of the modeled buildings. Specifically, comfort controls have an effect on height of future buildings, floorplan dimensions, density (coverage), and to some extent on land use, because a viable use of a structure is related to all the above-mentioned dimensions.

Effect of Comfort Controls on Density and Coverage

Coverage was considered a constant in our experiment. However, the modeling experiment revealed that comfort controls can constrain development potential depending on the variables discussed below. On most sites it was possible to match the floor space modeled under the potential development scenario with the floorspace modeled under the mitigated scenario. In areas with low-to medium-density, between two to four times the lot coverage, comfort controls have not affected densities, even along those streets for which five-hour sun access standards were proposed. The same finding was made in medium-density zoning districts. But here, small lots and especially lots located on the southeast and southwest corners facing east-west streets, were severely constrained by sun access controls. On lots with a typical depth of 30 to 40 meters comfort controls may constrain achievable densities to less than six times coverage. The coverage of six can be reached on north-south streets, for which a three-hour standard is proposed. Likewise, this coverage is possible on the north side of east-west streets.

In medium- to high-density areas (in our modeling, the properties along Bloor Street near Bay and Yonge Streets) densities can reach the allowable 6.5 coverage. Projects in this area consist generally of mixed-use developments located on medium- to large-size parcels with a depth of 70m or more. Such a mixed-use development would typically have retail and commercial uses located in a podium or building base. Residential floors would be located in a tower above such a podium. The density of this type of development, given the great depth of such properties, is constrained by the height limit and, to a lesser degree, by comfort controls.

In high-density areas, such as the Lake Front-Railway Lands, a density of twelve-times coverage cannot be reached by development that follows comfort controls. The maximum density possible under comfort controls would amount to ten times the coverage. The concern for light and calm winds in the interior block open spaces might further modify achievable densities. (A more reasonable building configuration -- shown in the implementation section -- would yield eight-times coverage).

A somewhat higher density then ten times coverage might be possible on the north side of east-west streets, if sponsors of such projects can demonstrate that future buildings would not accelerate the surface winds beyond comfort or even safety thresholds.

The high density of ten-times coverage assumes that each city block would house a combination of residential and commercial development. Residential development with retail at the ground level would line the east-west and north sides of city blocks, and the commercial development would be located in the southern section and in the center of a block, a location where sun access controls do not severely constrain the height of buildings. A second alternative in this high-density area is a development that would consist of an approximately ten-floor-high commercial building covering much of the entire block. Above this office and retail base, residential flats could be constructed. They would take the form of slabs or towers reaching up to the height limit or a limit set by sun access planes.

Effect of Comfort Controls on Floor Plan Dimensions

In areas zoned for low- to medium-high-density, comfort controls do not constrain floor plan dimensions on streets for which the three-hour standard is proposed, and for north-south streets for which the five-hour standard is proposed. On these streets, up to densities of four-times coverage, floorplan configurations were not constrained by comfort controls in our modeling. A range of dif-

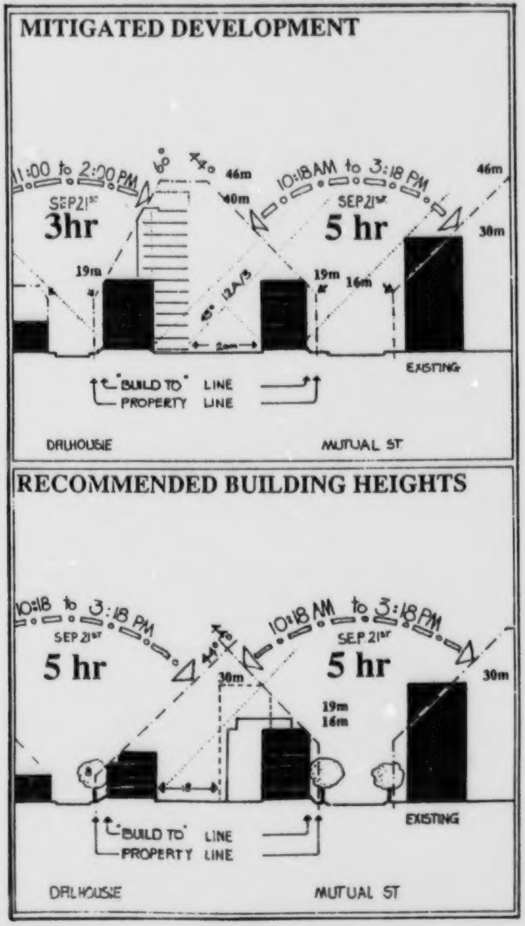

MITIGATED DEVELOPMENT
11:00 to 2:20 PM
SEP21ST
3hr
46m
40m
19m
12A/3
2m
10:18AM to 3:18 PM
SEP21ST
5 hr
46m
30m
19m
16m
EXISTING
"BUILD TO" LINE
PROPERTY LINE
DALHOUSIE
MUTUAL ST
RECOMMENDED BUILDING HEIGHTS
10:18 to 3:18 PM
SEP 21ST
5 hr
30m
10:18 AM to 3:18 PM
SEP 21ST
5 hr
30m
19m
16m
EXISTING
"BUILD TO" LINE
PROPERTY LINE
DALHOUSIE
MUTUAL ST

Fig 5.1

ferent floorplan designs were possible. The "build-to" line, however, forced building volumes into a type of development oriented toward streets (see Fig. 5.1.).

Above a density of four-times coverage, the "build-to" line, in combination with sun access planes, creates building volumes and floorplan dimensions that incorporate two types of orientations. Floors with units oriented either toward the street or toward the rear (double-loaded) would be built in a lower portion of a building. Above these floors, the sun access plane limits the floorplan dimension. Here narrower flats have both street orientation and orientation to the rear. The sun access planes prohibit a centering of these narrower floors above the wider floor. The result is an eccentric building design with upper floors shifted back towards the rear above the lower floors. Elevators and stairways serving all floors in such a building would be located in the center of the lower floors, but would be located in close proximity to the street-facing facade on the upper floors. Residential development would very likely take this form, if "build-to" lines are drawn identically with property lines along streets where retail is encouraged at ground level.

The floor plan dimensions of office space are not constrained by comfort controls if built up to the height of the streetwall permitted under sun access controls. Depending on lot dimensions, the floorplan dimensions of office buildings above this height will be constrained by comfort controls. Office towers with large floorplates of more than 2,000 square meters (40m x 50m) are possible but only in the center of large lots located on the south side of city blocks.

Effect of Comfort Controls on Building Heights

An obvious limit to building heights is set by sun access planes. However, buildings on properties along streets for which a three-hour standard is proposed are constrained by height limits to a greater extent than by sun access planes. Especially on north-south streets, the 60 degree sun access planes allow buildings on major portions of these properties to reach height limits of 30m, 46m, or 60m even on relatively small parcels measuring in depth not more than 50m. The same height limits will not be reached by future development along east-west streets and along all streets for which the five-hour standard would be proposed. The allowable building height on these properties (depth not more than 50m) would be constrained to a maximum of 18 to 20m.

Built Form Summary

Comfort controls severely constrain development in high-density districts.

In medium-density districts, comfort controls constrain development on most small lots, but not on medium- to large-size parcels.

In low- to medium-density districts, comfort controls do not constrain development. Here, they might encourage development on small parcels and discourage development on large parcels.

The interrelationship of these individual planning controls is complex. Height limits, density controls (coverage), sun access planes, and wind standards interact with one another and with other rules. Most importantly, in residential developments they interact with guidelines that protect privacy, light, and views. Together, these controls define built form. The proposed introduction of comfort controls would introduce a greater definition of built form. The greater definition would contribute to a better quality of the public environment -- specifically, a better quality of microclimate and comfort in public streets and open areas. The next section discusses the recommendation made by this study. If followed, these recommendations would significantly improve comfort for pedestrians and open space users in Toronto.

Railway Lands / Lakefront Area

Wind Tunnel Measurement Results

Existing Conditions

Pt. No.	Wind Ratio			
	NW	W	SW	E
1	0.964	0.636	0.549	1.056
2	0.379	0.675	0.627	1.137
3	1.009	0.495	0.948	1.005
4	0.942	0.992	0.444	0.531
5	0.771	0.861	0.292	0.897
6	0.588	0.715	0.326	1.18
7	0.633	0.692	0.208	0.473
8	0.557	0.71	0.687	0.451
9	0.582	0.803	0.928	0.476
10	0.63	0.747	1.049	1.01
11	1.108	0.523	0.651	0.369
12	0.97	0.701	0.559	0.655
13	0.938	0.871	0.395	0.322
14	0.998	1.091	0.672	1.1
15	0.911	1.183	0.849	1.08
16	0.777	1.203	0.895	1.082
17	0.218	0.532	0.794	0.802
18	0.605	0.835	1.125	0.849
19	0.687	0.493	1.032	0.692
20	1.166	0.969	0.602	0.91
21	0.831	0.8	0.713	0.914
22	0.904	0.869	0.353	0.902
23	0.709	0.78	0.246	0.861
24	0.637	0.877	0.616	0.618
25	0.548	0.94	0.682	0.877
26	0.963	0.944	0.297	0.969
27	0.988	0.406	0.263	0.769
28	0.58	0.725	0.416	0.782
29	0.471	0.686	0.59	0.774
30	0.514	0.871	0.406	0.395
31	0.537	0.915	0.552	0.415
32	0.456	0.726	0.474	0.615
33	0.513	0.778	1.011	0.411
34	0.785	0.416	0.662	0.508
35	0.609	0.242	0.43	0.476
36	0.67	0.614	0.747	0.611
37	0.669	0.6	0.794	0.52
38	0.684	0.896	0.759	0.626
39	0.727	0.837	0.787	0.701
40	0.688	0.89	0.849	0.748
41	0.795	0.933	0.894	0.787
42	0.783	0.913	0.918	0.812
43	0.8	0.873	0.878	0.816
44	0.785	0.895	0.822	0.833
45	0.811	0.888	0.92	0.901
46	0.776	0.95	0.923	0.839
47	0.712	0.98	0.917	0.762
48	0.649	0.933	0.908	0.731
49	0.648	0.878	0.895	0.655
50	0.725	0.829	0.858	0.409
51	0.527	0.836	0.828	0.439
52	0.511	0.764	0.96	0.697
53	0.723	0.565	0.477	0.337
54	0.743	0.802	0.648	0.334

Potential Development

Pt. No.	Wind Ratio			
	NW	W	SW	E
1	0.964	0.762	0.559	1.127
2	0.319	0.761	0.675	1.232
3	0.554	0.524	0.981	1.013
4	0.549	1.073	0.356	0.47
5	0.5	1.009	0.287	0.874
6	0.351	0.947	0.297	1.14
7	0.575	0.687	0.538	0.41
8	0.568	0.902	0.34	0.349
9	0.47	0.732	0.729	0.338
10	0.771	0.854	0.61	0.973
11	0.515	0.383	0.668	0.374
12	0.473	0.627	0.636	0.659
13	0.413	0.799	0.348	0.308
14	0.396	1.17	0.75	1.097
15	0.468	1.34	0.846	1.069
16	0.308	1.361	0.859	1.111
17	0.132	0.472	0.878	0.828
18	0.31	0.851	1.158	0.857
19	0.471	0.415	1.051	0.718
20	0.619	0.604	0.529	0.834
21	0.474	0.54	0.639	0.516
22	0.595	0.267	0.354	0.71
23	0.764	0.276	0.356	0.445
24	0.904	0.498	0.372	0.835
25	0.796	0.256	0.35	0.465
26	0.428	0.324	0.32	0.867
27	0.564	0.208	0.348	0.709
28	0.34	0.53	0.457	0.769
29	0.355	0.74	0.486	0.75
30	0.324	0.88	0.995	0.431
31	0.349	0.943	0.685	0.407
32	0.285	0.794	0.719	0.49
33	0.52	0.77	0.646	0.474
34	0.705	0.87	0.657	0.515
35	0.293	0.25	0.625	0.446
36	0.594	0.553	0.784	0.499
37	0.541	0.683	0.772	0.339
38	1.045	0.591	0.321	0.394
39	1.105	0.941	0.683	0.3
40	0.924	0.884	0.949	0.388
41	0.84	1.068	0.75	0.342
42	1.192	1.291	0.455	0.483
43	0.766	1.184	1.203	0.514
44	1.005	1.113	1.051	0.539
45	0.878	1.047	0.96	0.521
46	1.309	1.144	1.151	0.549
47	0.865	1.04	0.846	0.549
48	1.147	0.727	0.772	0.635
49	1.111	0.914	0.879	0.295
50	1.326	0.872	0.569	0.367
51	0.43	0.753	0.633	0.419
52	0.404	0.498	0.723	0.689
53	0.624	0.421	0.359	0.149
54	0.651	0.87	0.752	0.449

Mitigated

Pt. No.	Wind Ratio			
	NW	W	SW	E
1	0.721	0.692	0.487	1.052
2	0.324	0.717	0.626	1.181
3	0.514	0.447	0.874	1.002
4	0.546	0.85	0.325	0.434
5	0.519	0.804	0.258	0.887
6	0.519	0.617	0.242	1.128
7	0.459	0.487	0.493	0.39
8	0.791	0.501	0.306	0.36
9	0.423	0.584	0.644	0.311
10	0.564	0.674	0.539	0.859
11	0.56	0.433	0.627	0.313
12	0.419	0.375	0.625	0.651
13	0.555	0.468	0.355	0.303
14	0.667	1.056	0.753	1.09
15	0.662	1.224	0.793	1.08
16	0.68	1.196	0.818	1.107
17	0.18	0.454	0.829	0.824
18	0.21	0.793	1.049	0.816
19	0.382	0.356	0.989	0.668
20	0.707	0.641	0.512	0.664
21	0.461	0.554	0.667	0.761
22	0.508	0.493	0.313	0.576
23	0.435	0.465	0.194	0.618
24	0.669	0.557	0.347	0.594
25	0.253	0.163	0.461	0.513
26	0.46	0.588	0.24	0.736
27	0.448	0.297	0.39	0.695
28	0.384	0.529	0.367	0.753
29	0.34	0.578	0.346	0.783
30	0.427	0.776	0.889	0.453
31	0.465	0.919	0.706	0.333
32	0.338	0.573	0.776	0.517
33	0.364	0.252	0.976	0.856
34	0.846	0.265	0.713	0.427
35	0.394	0.191	0.319	0.466
36	0.375	0.564	0.462	0.595
37	0.113	0.483	0.41	0.239
38	0.669	0.694	0.48	0.239
39	0.383	0.43	0.122	0.349
40	0.905	0.42	0.254	0.397
41	0.628	0.664	0.529	0.272
42	0.328	0.401	0.371	0.395
43	0.605	0.664	0.848	0.349
44	0.885	0.866	0.522	0.423
45	1.035	0.964	0.378	0.633
46	0.843	0.734	1.02	0.524
47	0.429	0.624	0.73	0.287
48	0.874	0.759	0.873	0.357
49	0.45	0.519	0.579	0.343
50	0.734	0.684	0.238	0.272
51	0.815	0.559	0.375	0.313
52	0.412	0.407	0.466	0.279
53	0.678	0.421	0.308	0.226
54	0.624	0.777	0.645	0.322

6. RECOMMENDATIONS

Current policy of the City of Toronto with regard to preservation of comfortable conditions for pedestrians is summarized in the following current Official Plan Statements:

1A, 41(a) Be it the policy of Council to encourage the retention, development, and enhancement of public streets and streetscapes which have well-defined character, scale, and enclosure, to ensure that they are comfortable and convenient and offer varied activities and experiences to pedestrians.

31A, 48 In order to achieve an improved pedestrian environment at and around street level in the Central Area, Council will seek to ensure satisfactory conditions with respect to wind and calm and sun and shade. In doing so, Council will seek to alleviate existing problems of high wind velocities and lack of sun in important pedestrian areas caused by the height or inappropriate space or configuration of buildings, and to prevent the worsening of such conditions. In using its power of regulation and review in implementing this section, Council will apply objective standards and determine satisfactory conditions.

> **This study confirms that this policy is valid, and, in order to implement these policies, it recommends specific planning controls, standards, and guidelines.**

The research presented in this report confirms that direct sunlight and protection from wind are essential for pedestrian comfort during the spring and fall season in Toronto. During the long winter, sunlight is beneficial, but low angles of the sun frequently do not provide sufficient radiation to compensate for cold air temperatures and wind. During the summer, high air temperatures, combined with humidity, will frequently provide uncomfortable conditions.

> **Planning controls that prevent the worsening of climatic conditions for pedestrians would be most effective if they would address mandatory provisions for sun access during the spring and fall seasons, as well as protection from strong wind year-round.**

6.1 Sun Access for Streets in the Central Area

It is the recommendation of this report that, during midday hours, all streets should have the benefit of sun access during the time between the spring and fall equinox. This recommendation is based on the fact that direct sun radiation to the human body can extend the period of comfortable conditions for pedestrians by several months, even at times when air temperatures are cool or moderate. Second, the field analysis conducted as part of this study confirms that the great majority of all north-south and most east-west streets in the Central Area receive sunlight during midday for a period of three hours at the spring and fall equinox. Many streets receive five or even seven hours of sunlight at that time of day and year.

Three categories of sun access windows are proposed: three, five, and seven hours of sun access to at least one sidewalk. The three-hour period was chosen as a minimum to provide comfortable conditions during the lunch hour, when most people use streets in the Central Area.

6.1.1 Street Classification System

The responsibility of the time window assignment rests with the City of Toronto. To ease the process, we have established classifications of streets in Toronto's Central Area that categorize the different streets according to their importance in use and symbolic value. The classification shown in Fig 6.0 is given as a guideline. Further studies are needed to assess and classify all streets in the Central Area. For north-south streets, the midday period is defined as the time window between 11 a.m. and 2 p.m. D.S.T. on the 21st of September. For east-west streets, the midday period starts at 12:18 p.m.D.S.T., on the same date. Strictly speaking, the three-hour midday period for east-west streets would end at 3:18p.m.; in fact, however, the sun will continue to reach into east-west streets after that time at the fall equinox.

Recommendations:

> **Adopt a street classification standard for all streets of the Central Area. Assess and classify all streets or sections of streets into categories according to the duration of sunlight that each street shall receive. The categories are three, five, or seven hours of sun access for a period of time encompassing midday on September 21st.**

Three-hour Time Window

This study recommends a three-hour time window for the following street classification:

Business Streets
Business streets include all streets that are not otherwise defined in the categories below.

Five-hour Time Window

This study recommends a five-hour time window for the following street classifications:

Promenades
These are streets and avenues that have a special significance on a city-wide basis, where people stroll and enjoy the outdoor environment of city life at extended times of the day. Such streets are institutional environments in their own right, such as University Avenue, or are destination streets that bring large numbers of people to recreational opportunities, such as the ferry docks, harbourfront, or scenic routes such as Queens Quay.

A high degree of climatic comfort ought to be available for longer periods on such streets, and therefore the five-hour window should be assigned to promenade streets. A north-south street, University Avenue, and an east-west street, Queens Quay, would fall into this category.

Historic Streets
These are streets that have a special identity through character, scale or the preservation of significant historical buildings in a district. They are often attractive to tourists and people with leisure time. Streets of this kind are Front Street east of Scott Street, and Queen Street east of Church Street or west of University Avenue, and Yonge Street north of Queen.

Because a high degree of comfort ought to be afforded to such streets, a five-hour window should be assigned to historic streets.

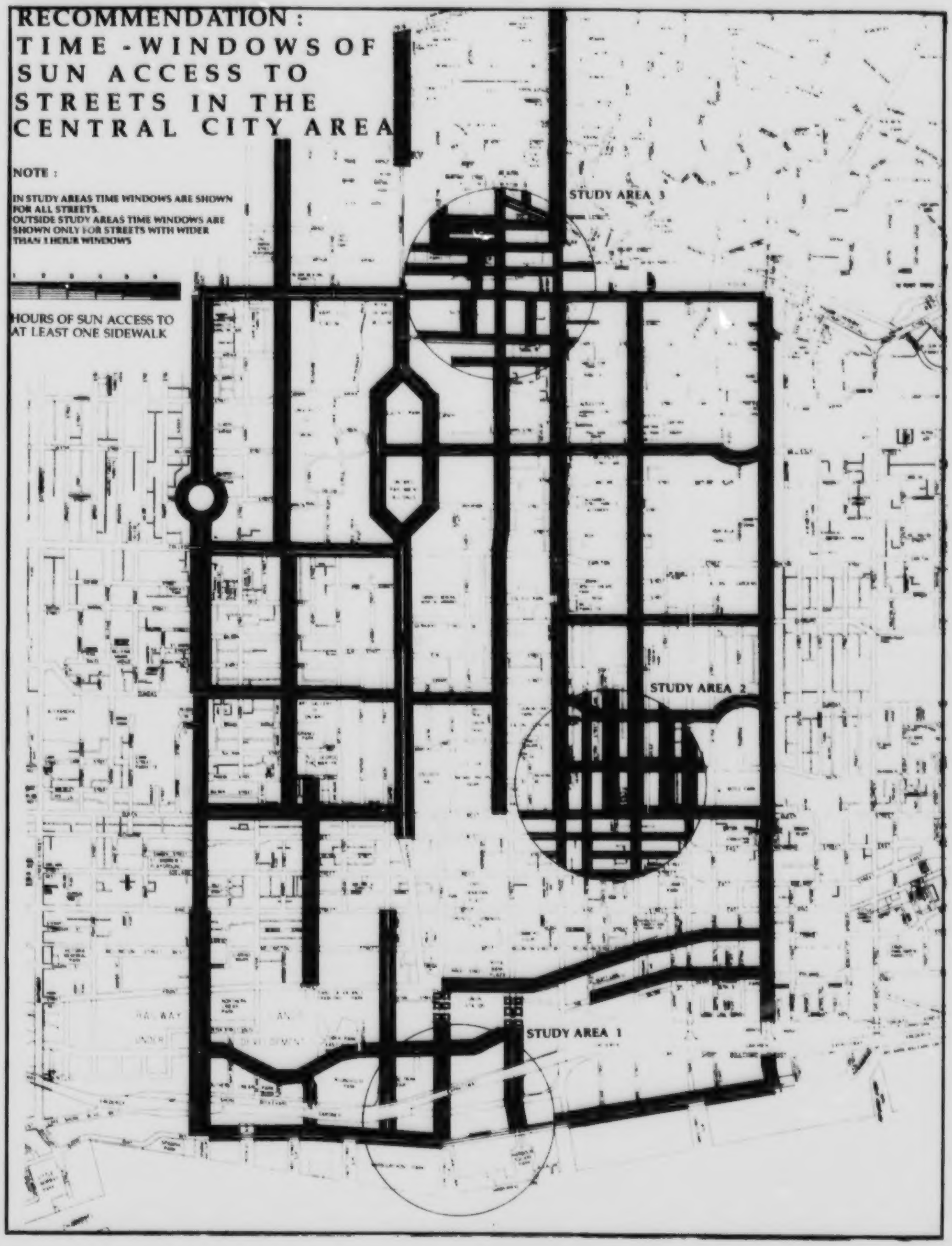

RECOMMENDATION :
TIME -WINDOWS OF SUN ACCESS TO STREETS IN THE CENTRAL CITY AREA
NOTE :
IN STUDY AREAS TIME WINDOWS ARE SHOWN FOR ALL STREETS.
OUTSIDE STUDY AREAS TIME WINDOWS ARE SHOWN ONLY FOR STREETS WITH WIDER THAN 1 HOUR WINDOWS
HOURS OF SUN ACCESS TO AT LEAST ONE SIDEWALK
STUDY AREA 3
STUDY AREA 2
STUDY AREA 1

Fig 6.0 Proposed Sun Access Standard. Streets with five or more hours of sunlight during midday.

Main Streets
Main streets are generally major east-west streets, and a number of north-south streets, that mark the larger grid of the City and divide the City into neighborhoods. Their intersections are key orientation points for the public. Most of these streets are shopping streets, on a local or regional level. They lead to and from neighborhoods and provide city-wide linkage.

All of these streets are well recognized and of public significance. Streets of this type are Bloor Street west of Spadina, and Dundas Street west of St. George, and Yonge Street.

Main streets have also been assigned the five-hour window, due to their regional and local significance.

Medium-density residential streets and mixed-use streets
Residential streets are streets that serve a large residential component. They are used by people going to work or shopping, and often by children. They lead to schools, community facilities, and open spaces such as parks and playgrounds. All streets with a residential component are assigned at least a five-hour window of sun penetration.

Seven-hour Time Window

Low-density residential streets
These streets are typical residential streets with two- to three-story buildings which require climatic comfort during most of the day, when people go to work and children to school, from morning until 5:30 p.m.

6.1.2 Sun Access Standards for Streets

Recommendation:

> **Restrict the allowable height of future development to guarantee three or more hours of sunlight during the midday period between the spring and fall equinox.**

Three-Hour Windows of Sunlight on North-South Streets

The study recommends that sun access criteria allow direct sunlight to reach the sidewalks for a minimum of three hours between 11 a.m. and 2 p.m. D.S.T at the fall equinox. In order to maintain direct sunlight on public sidewalks in the Central Area during this three-hour period, new structures and additions to existing structures on parcels that abut the side of a street shall be required to avoid penetration of a sun access plane. This plane is defined by an angle sloping away from the street above a specified height at the property line. For properties along north-south streets, a plane sloping at 60 degrees will set allowable building heights at the property line and for portions of the property until the sun-access plane reaches the established height limit of the district in which the property is located.

The allowable height at the property line is dependent upon the width of the street. On a typical 20m wide street, the height at the property line would result in 31m. Above this height, building volumes would be set back, following a plane sloping at 60 degrees. The allowable height at the property line is the "streetwall height," and the streetwall projects upward vertically from the property line. Streetwall heights for streets

FIG. 6.1

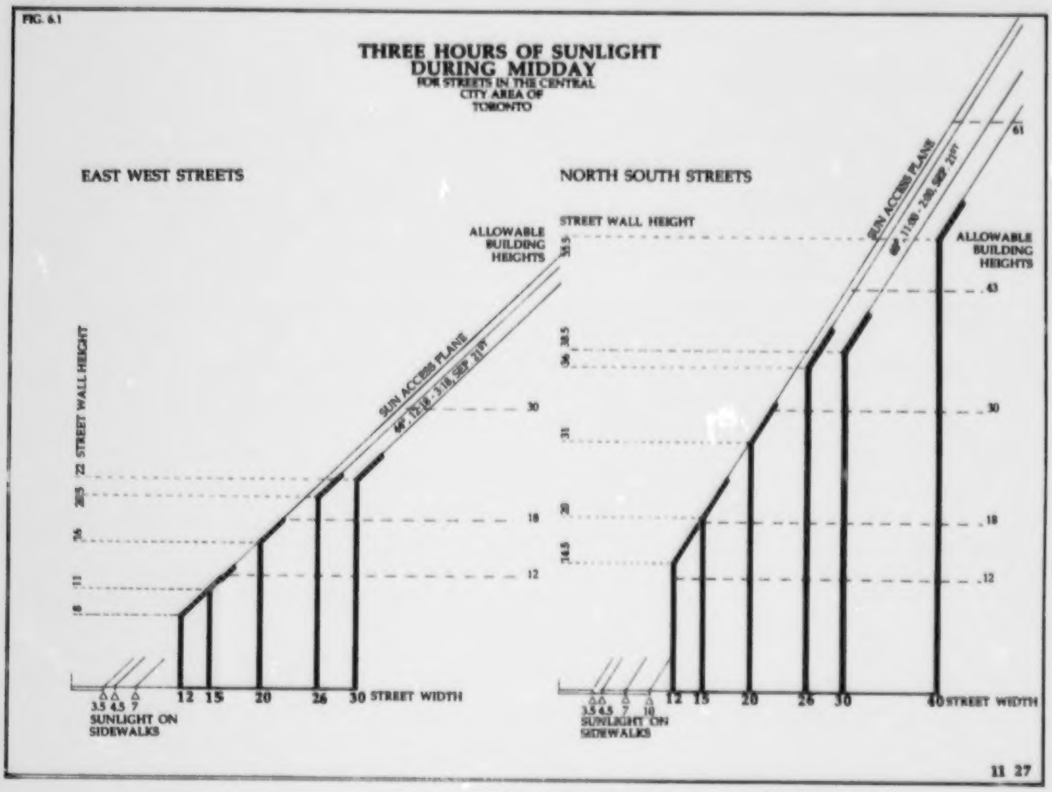

THREE HOURS OF SUNLIGHT
DURING MIDDAY
FOR STREETS IN THE CENTRAL
CITY AREA OF
TORONTO
EAST WEST STREETS
NORTH SOUTH STREETS
STREET WALL HEIGHT
ALLOWABLE
BUILDING
HEIGHTS
SUN ACCESS PLANE
44°, 12:18 - 3:18, SEP 21ST
48°, 11:08 - 2:08, SEP 21ST
18
11
16
20.5
22
35.5
24.5
20
31
36
38.5
12
18
30
43
61
12 15 20 26 30 STREET WIDTH
12 15 20 26 30 40 STREET WIDTH
3.5 4.5 7
3.5 4.5 7 10
SUNLIGHT ON
SIDEWALKS
11 27

Fig. 6.1 Sun Access Standard.
Three Hours of sunlight encompassing the Midday Period from March 21st to September 21st.

of varying street width are shown in Fig. 6.1.

Buildings constructed in this manner will preserve sunlight on the sidewalk across the street. Together, the western and the eastern sidewalk will receive a total of three hours of sunlight. The sun access plan in Fig. 6.1 shows various sidewalk dimensions. The sidewalk dimensions are based upon the width of streets. For example, future buildings on 25m or narrower north-south streets should maintain sunlight to a sidewalk dimension of 3.5m in width, and for buildings on streets between 25m and 29m in width, sunlight should be maintained to a sidewalk width of 4.5m. Future buildings on streets between 29m and 39m should maintain sunlight for a sidewalk width of 7m. Buildings on streets wider than 39m should maintain sunlight on sidewalks of 10m in width. These dimensions for sunlight penetration are recommended regardless of the actual width of the sidewalk.

Three-Hour Windows of Sunlight for East-West Streets

The study recommends sun access standards that allow direct sunlight to reach the sidewalks during the midday period starting at 12:18 D.S.T. on the fall equinox. (At 11:18 EST on the spring equinox). For properties on the south side of east-west streets, a sun access plane of 44 degrees will set allowable building heights at the property line and continue to set heights for portions of the property until the 44 degree plane reaches the already established height limit of the district in which the property is located. The allowable height at the property line is dependent upon the width of the street. On a typical 20-meter-wide street, the height at the property line would result in a streetwall height of 15.5 meters. Streetwall heights for streets of varying street widths are shown on Table 6.1. The same sidewalk width dimensions explained above for north-south streets should be used for east-west streets.

The height of properties on the north side are exempted from the sun access criteria because the penetration of the plane (for obvious reasons) does not create shadows at midday. Nevertheless, properties on the north side of east-west streets should follow the identical streetwall height requirements set for properties across the street. The rationale for this restriction has to do with the fact that building setbacks above the streetwall are beneficial to wind velocity reductions. Downwinds created by building facades are mitigated by building setbacks at the streetwall height. This setback dimension shall amount to a minimum of six meters. At this distance from the property line, a building height is free to reach the established height limits of the district in which the property is located. These setback dimensions should be increased if wind tunnel studies indicate the need for a larger setback in order to meet approved wind standards. For example, wind tunnel studies of buildings in the 137m height district indicated that a setback dimension of 20m above the streetwall height of 30m was necessary to mitigate against winds that would otherwise be directed downwards from such building heights to sidewalk level. A mandatory setback above the streetwall height encourages symmetrical street sections for east-west streets.

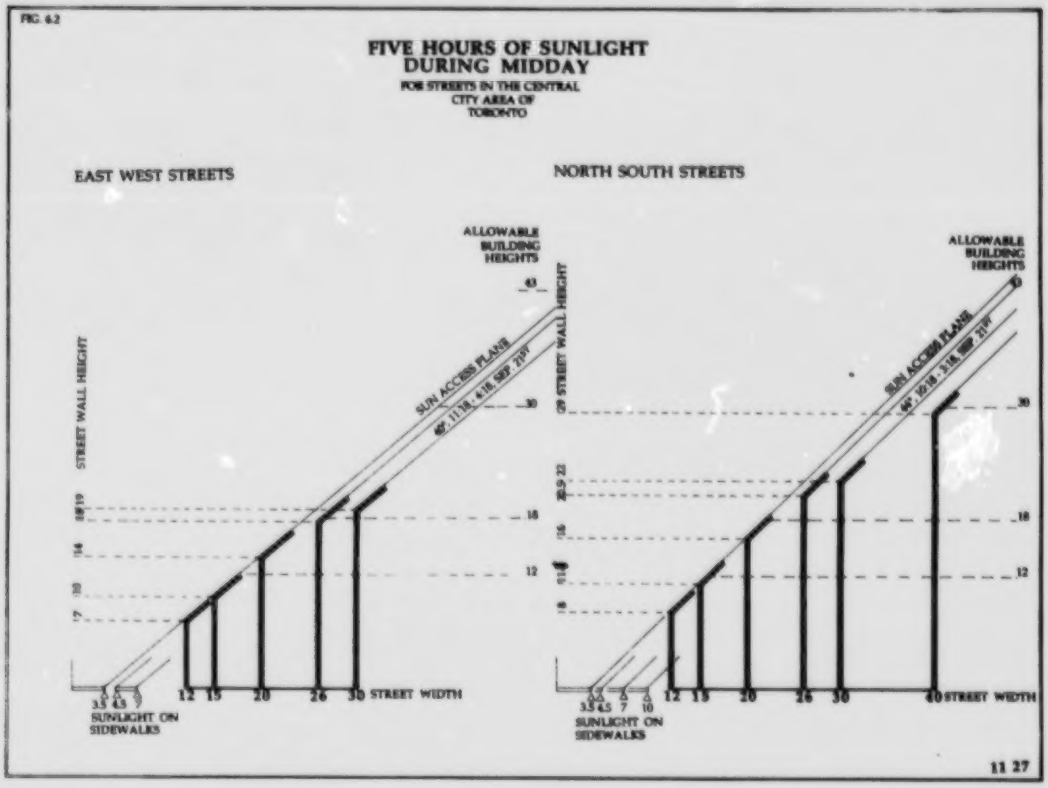


FIG. 6.2
FIVE HOURS OF SUNLIGHT DURING MIDDAY
FOR STREETS IN THE CENTRAL CITY AREA OF TORONTO
EAST WEST STREETS
NORTH SOUTH STREETS
ALLOWABLE BUILDING HEIGHTS
STREET WALL HEIGHT
SUN ACCESS PLANE
40°, 11:18 - 4:18, SEP. 21ST
44°, 10:18 - 3:18, SEP. 21ST
43
30
18
12
7
10
14
18 19
8
11
16
20.9 22
29
12
15
20
26
30
40
STREET WIDTH
3.5
4.5
7
10
SUNLIGHT ON SIDEWALKS
11 27

Fig. 6.2 Sun Access Standard.
Five Hours of Sunlight During the Midday Period from March 21st to September 21st.

Five-Hour Window for Streets in the Central City Area

For north-south streets, the duration of the five-hour window of sunlight during midday shall be set for 10:18 a.m. to 3:18 p.m., D.S.T., on the 21st of September. The slope of the sun access plane measures 44 degrees. (Note: The five-hour standard for north-south streets produces streetwall height dimensions and sun access plane angles identical to the three-hour standard for east-west streets.)

For east-west streets, the five-hour time window starts at 11:18 a.m. D.S.T. on the 21st of September. The slope of the sun access plane measures 40 degrees. This five-hour time window should be applied to streets in the Central Area that are predominantly residential or are more heavily used by pedestrians for leisurely strolling or window shopping during late morning and afternoon hours.

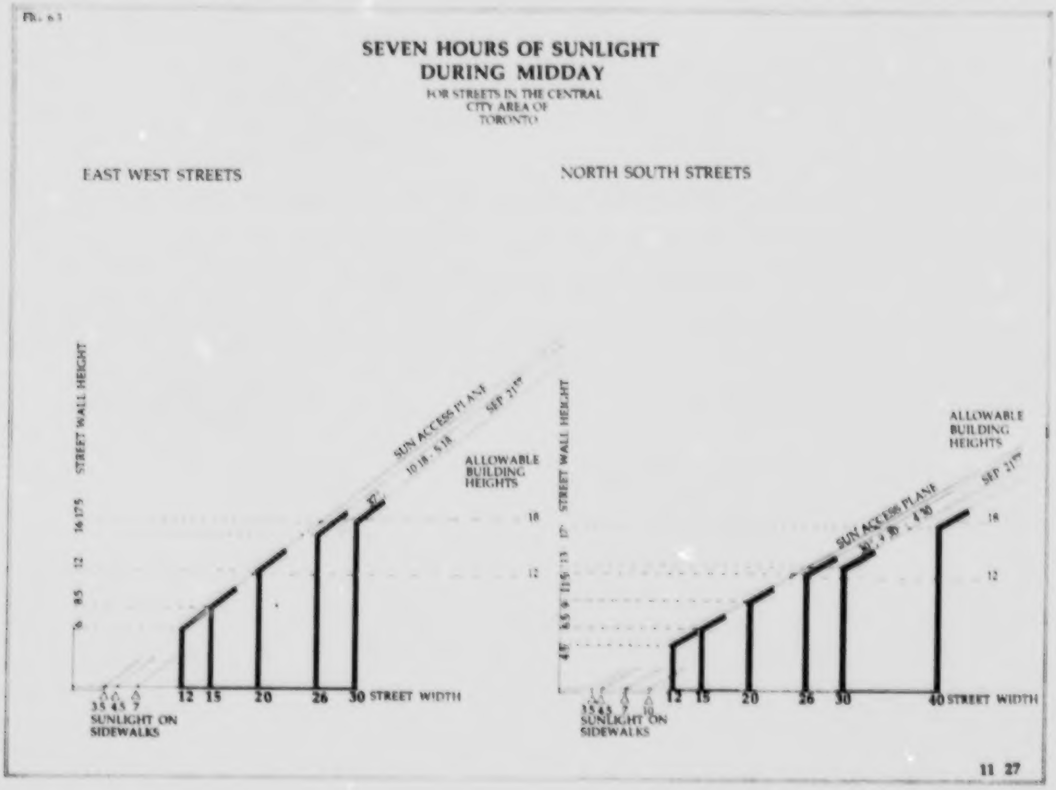


Fig. 6.3
SEVEN HOURS OF SUNLIGHT
DURING MIDDAY
FOR STREETS IN THE CENTRAL
CITY AREA OF
TORONTO
EAST WEST STREETS
NORTH SOUTH STREETS
STREET WALL HEIGHT
6
8.5
12
16 17.5
SUN ACCESS PLANE
10 18 - 5 18
SEP 21st
37°
ALLOWABLE
BUILDING
HEIGHTS
18
12
12
15
20
26
30
STREET WIDTH
3.5
4.5
7
SUNLIGHT ON
SIDEWALKS
STREET WALL HEIGHT
4.5
6.5
9
11.5
13
17
SUN ACCESS PLANE
30°, 9 30 - 4 30
SEP 21st
ALLOWABLE
BUILDING
HEIGHTS
18
12
12
15
20
26
30
40
STREET WIDTH
3.5
4.5
7
10
SUNLIGHT ON
SIDEWALKS
11 27

Fig. 6.3 Sun Access Standard.
Seven Hours of Sunlight During the Midday Period from March 21st to September 21st.

Seven-Hour Windows of Sunlight for Streets in the Central City Area

For north-south streets, the duration of the seven-hour window of sunlight during the midday period shall be set from 9:30 to 4:30 D.S.T. on the 21st of September. The slope of sun access plane measures 30 degrees. For east-west streets, the seven-hour time window starts at 10:18 a.m. and lasts until 5:18 p.m. on the 21st of September, when the sun is aligned with the street. At 10:18 a.m. the slope of the sun access plane measures 37 degrees.

6.1.3 Implementation of Sun Access Controls for Streets

Height Limit Versus Performance Standards

Planning regulation mandating sun access planes can be implemented in a number of ways. In principle, there are two methods. One option is to use sun-access planes as height limits, modifying the existing height limits of a zoning district. Future buildings are designed to follow the streetwall height and sun access plane in that portion of the site where sun access requirements are lower than the existing height limit. At the point where the sun access plane intersects with the height limit, the existing height limit takes over in regulating the allowable building height. Building heights on properties may be defined by several sun access planes, if a property is located at the corner of a block or if a property penetrates through the entire length and/or width of a city block.

The second method of implementing sun access to streets is by legislating performance standards. Here, a sponsor of a development on a given property would have to demonstrate that a proposed building does not cast shadows onto abutting streets during the time period protected by the sunlight ordinance. However, if a neighboring building already in existence casts shadows on a section of sidewalk that would be shaded if the proposed building penetrates the sun access plane, the sponsor of this proposed property would be entitled to construct such a building as long as it does not cast any additional shadows. In other words buildings could be built that exceed the streetwall heights and the sun access plane as long as these buildings remain within a "shadow envelope" of neighboring buildings. A somewhat unpredictable building form and street section results, if performance standards are used to implement sun access criteria.

This study recommends the use of zoning height limits for the implementation of sun access controls. The rationale for this recommendation is twofold. First, the administration of a sunlight ordinance that relies on height limit is considerably easier than the administration of an ordinance that utilizes a performance standard. If a performance standard were used, the Department of Planning and Development would need to verify the accuracy of all shadow studies of proposed as well as of existing structures. This process would only be feasible if an accurate, three-dimensional computer database of the Central Area were available. The accuracy of the database currently used would not be adequate.

The currently used database does not represent the actual topography of streets and open spaces. Also, the accuracy of existing building dimensions and precision of their representation differs greatly. According to our experience with such databases, an input accuracy of +/- 10cm for all horizontal and vertical building dimensions results in an acuracy of +/- 1.5m for all shadow dimensions on the ground. Given that sidewalks measure 3.5m, the +/- 10cm accuracy criterion appears to be reasonable, but is not met by the database currently in use.

The second reason for recommending height limits to implement sun access to streets is related to a clearer implementation policy than currently exists. Height limits that would guarantee sun access to streets would set a clear signal to the community that city government intends to depart from the discretionary nature of its review procedure to a mandatory approach

Recommendation:

> **Review and revise the zoning height limits and density controls in the Central Area of Toronto. Set the revised density controls of each district to be compatible with the revised height limit of the same district.**

Once established, the new zoning heights will no longer be subject to discretionary review in negotiations between the sponsor of future development and the City of Tornoto. The revised height limits are further modified by the height restrictions imposed by the proposed Street and Open Space standards.

Effect of Sun Access Controls on Building Shapes and on Other Planning Controls

Members of the architectural design community might object to the sloping facade or roof planes that would result from an ordinance mandating sun access to streets. One method that can be used to avoid sloping facade planes above the streetwall is to mandate a setback at that height where the sun access plane meets the streetwall. Contextual zoning on Manhattan's Upper West Side requires setbacks of 6.75m above the streetwall height of 20m on 20m-wide side streets. Additional floors can be erected at that setback line, but have to remain under a sloping plane taken from the center line of the street. Likewise in Toronto, portions of buildings above the streetwall line would require setbacks. Additional floors could be built, but have to remain under the sun access plane.

Concerns about the shape of buildings stem from a potential conflict between the various planning controls restricting the form of a proposed building. These controls would include height limits, sun access planes, lot coverage, and density controls. In all cases, height limits should supersede density controls and constrain the allowable building volume. This statement appears obvious, but in the modeling of potential development, allowable volume of a building as defined by lot coverage and density controls frequently exceeded height limits, by a substantial margin. Therefore, the lot coverage and density controls must be reviewed and made more compatible with existing height limits.

This is made possible by computing building volumes under density and lot coverage controls for an average lot dimension in a given zoning district. If several building volumes have been computed for a number of sites, a "building potential" line can be drawn into a section view of that zoning district. When the height of this line is compared with the height limit of the district, the height limit should be well above such a "building potential" line. If the building potential line is above the height limit, zoning of the district should be reexamined. This might result in either an increased height limit or a decreased lot coverage and density control.

6.2 Sun Access to Open Space in the Central Area

Publicly owned and publicly accessible open space provides a significant resource for city residents. These spaces exist at a variety of sizes and in a variety of contexts. On a regional scale, open spaces like a valley system or lakeshore often define the spatial organization of the city. At the smallest scale, open spaces are shaped by the forms and densities of urban development. Public open spaces are usually developed in support of a range of activities, such as sitting, observing, play, gathering, or more organized outdoor recreational pursuits. In this role they act as the interface between the public and private realms, allowing freedom of movement and social interaction.

"Onbuildingdowntown" (Second Edition, 1974, p. 121) identified four major roles for open space in terms of use, providing:

> Areas for individual relaxation
>
> Visual relief
>
> Space for individual activity and group activity; and
>
> Space for both organized and spontaneous public gatherings.

In addition, public open spaces are also considered as indicators of a healthy environment and as "green lungs" within cities in which urban pollution has now become a major issue. Considering the importance of parks for providing unique cultural and environmental opportunities to the public, a fundamental right of access to sunlight and shelter from inappropriate wind impacts seems consistent with the roles of existing and future parks.

6.2.1 Open Space Classification as a Basis of Sun Access Standards

Parks exist in a variety of sizes from large regionally connected pieces of lands like the Toronto ravines to small pocket parks that occupy small spaces between buildings. In order to identify appropriate standards for sun access, some typological framework should exist which can relate the goals of the open space to the desired level of sun access and wind protection.

This report has used as a basis for this development a classification under study by the City of Toronto. In the proposed typology, open spaces are first broken down into five broad categories:

1. Regional Parks

Large-scale areas utilized by regional populations

2. Linear Parks

Ravine lands, bike paths etc

3. City Parks

Usually full block areas

4. Urban Parks

Green spaces surrounding public buildings

5. Pocket Parks

Small spaces between buildings, corners, etc

As well as these more broadly defined areas, the classification recognizes that public open space opportunities exist in other configurations such as:

1. Courtyards

Spaces surrounded by buildings intended for public use

2. Forecourts

Public open spaces next to streets, often acting as entrances to buildings

3. Setbacks

Public open spaces provided as a result of locating buildings back from property lines

4. Urban Gardens

Special public spaces where the emphasis is on more ornamental plant displays or special uses such as sculpture

5. Plazas/Squares

Larger public open spaces usually formal in layout often adjacent to public buildings and/or streets, intended for gathering, informal recreation and ceremonial use

Classification of Open Spaces in Terms of Thermal Comfort

Unlike streets, it is more difficult to generalize about park characteristics due to their variety of orientations, proximity to buildings, density/height relationships of surrounding urban development, dimensions and configuration of site boundaries, and variations in site elevations. Like streets, however, we can begin to identify, based on the classification of parks, desirable performance standards for solar access at new parks and for protecting access at existing parks.

Ideally, public open space should have optimum climatic conditions for human comfort and provide for a maximum flexibility of use. For open spaces in Toronto, this would mean providing access to sunlight throughout the year while minimizing wind impacts. This is particularly critical in the colder spring, fall, and winter months.

The objective in any open space design should be to maximize the total number of hours of sunlight available to the open space. The standards proposed here have been developed to reflect the conditions for parks studied in each class or type. However, standards should be tailored to the needs of the individual park, its physical context and program of use, such as ensuring that play areas are in the sun in the spring and fall, that floral displays get adequate sunlight, etc. Each open space requires individual study in order to determine the maximum available sunlight, the effects of existing conditions, the impacts on proposed programs, and the specific alternatives available within the proposed height controls.

The standards that follow should be considered as minimum, and the planning objective should be to exceed the standards whenever possible.

6.2.2 Standards for Different Types of Open Spaces

Recommendation:

> **Restrict the allowable height of future development in the vicinity of publicly accessible open spaces in order to preserve sunlight during those times of year and day when it is most needed for the comfort of open space users.**

City Parks

While all public parks are city parks, this proposed type seeks to identify large parks in the city usually surrounded by major streets and often a city block in size, or at least the major portion of a block. These areas are identified by the public as important open spaces and are heavily used by a variety of people engaged in passive or active recreation. They usually have large amounts of green space and form an important part of local identity within the surrounding community. Parks such as Allan Gardens or Roundhouse Park sometimes include facilities, such as the conservatory in the former and the future railway museum in the latter. In the Central Area, parks such as Roundhouse Park represent substantial investments in planning, capital, and the allocation of space. Opportunities for such large spaces are usually rare and therefore should have the highest degree of climatic comfort. Examples within our study of city parks are Allan Gardens, Roundhouse Park, and the Grange Park.

Solar Access Standards

City Parks are to receive direct sunlight over the entire year from one-and-a-half hours after sunrise to one-and-a-half hours before sunset.

Exempt from this standard are buildings which abut the park properties or front streets adjacent to park properties. Building heights on such properties should be set according to height limits set for adjacent streets.

In general, building heights up to 12m should be allowed for a park in a low-density residential area, heights up to 18m should be allowed adjacent to a park in medium-density areas, and 30m in a high-density area. Existing buildings that exceed the height limit are exempt.

SPECIFIC RECOMENDATIONS:

1. Allan Gardens

Permit building up to a height of 12m on properties abutting the park and on properties across the street from the park with the exception of Carlton Street, where the rules pertaining to sunlight access for streets may be applied. The allowable heights of buildings located at a distance of 300m from the park will follow a cut-off plane that does not permit shading of the park in excess of the shadow already cast by the permitted height of buildings adjacent to the park.

2. Grange Park

Permit building up to a height of 12m on properties abutting the park and on properties across the street from the park with the exception of the east side of McCaul Street, where a 24m exemption is granted. Above these designated levels, heights of buildings within a 300m distance of the park will follow a cut-off plane that does not permit shading of the park in excess of the shadow already cast by the permitted building heights.

3. Roundhouse Park

Permit building up to a height of 30m on properties abutting the park and on properties across the street from the park. Above these levels, building heights within 300m of the park will follow a cut-off plane that does not permit shading of the park in excess of the shadow already cast by the allowable height of the buildings abutting the park properties.

Linear Parks

Linear parks, like streets, act as a secondary form of pedestrian connection within the city. These parks can be associated with natural open space systems such as the ravine lands and usually connect with other open spaces. At the same time, the type describes spaces as simple as bike pathways, pedestrian routes along the lake's edge, or more elaborate walkways between buildings in the city, like Osgoode Mall. This secondary network of pedestrian circulation provides a unique opportunity for travel within the city. Opportunities for comfortable conditions should be maximized to protect natural features and to encourage pedestrian and bike use. Because of the diversity of spaces, topography, and dimensions of linear parks sun access should be preserved for the highest use areas. Examples of linear parks within our study area are Rosedale Valley Ravine and Osgoode Mall.

Solar Access Standards

Because linear parks are not always consistent in their size, configuration, and orientation, it is difficult to set one standard. However, natural areas and ravines should be protected to ensure adequate solar access to natural systems and to mitigate the impacts of shading along slopes as shadow lengths increase down slopes.

All natural areas should have sun access from one-and-a-half hours after sunrise to one-and-a-half hours before sunset (D.S.T.) from the spring to the fall equinox. For Linear Parks not studied in this report we recommend individual studies be undertaken for each park so that local conditions and programs can be taken into account.

SPECIFIC RECOMMENDATIONS:

1. Rosedale Valley Ravine

Permit building up to a height of 12m on properties abutting the Ravine. Above this height, heights of buildings within 300m distance of the park will follow a cut-off plane that does not permit shading of the ravine. Existing buildings that exceed the height limit are exempt.

2. Osgoode Mall

Permit building up to height of 18m on properties abutting the mall. Above this level, heights of buildings within a 300m distance of the park will follow a cut-off plane that does not permit shading of the mall at any time between the hours of 10:18 a.m. (D.S.T.) and 4:18 p.m. (D.S.T.) from the spring to the fall equinox in excess of the shadow created by buildings of the 18m permitted height.

Pocket Parks

These spaces are usually small and are often located in spaces vacated by buildings, remnants of old corner lots, street closures, etc. Because of their small size, proximity to buildings, and location on the east, west, north, or south sides of streets, it is difficult to set standards for solar access to fit all pocket parks. The microclimatic conditions on these sites will be heavily dependent on the standards applied to adjacent streets and future developments in specific locations that may reduce solar access to these areas. Examples of pocket parks studied are Devonian Park, Cumberland Park, and Maple Leaf Quay.

Solar Access Standards

Pocket parks are often built in very small and restrictive conditions. Sites along corners and wider streets have greater opportunities for solar access than small spaces between buildings. Sun access should be maximized whenever possible.

Pocket Parks should have a minimum of three hours of sun from 11:18 a.m. (D.S.T.) to 2:18 p.m. (D.S.T.) from the spring to the fall equinox. For Pocket Parks not studied in this report we recommend individual studies be undertaken for each park so that local conditions and programs can be taken into account.

SPECIFIC RECOMMENDATIONS:

1. Cumberland Park

The site set aside for the proposed Cumberland Park lost its sun access due to recently approved developments along Bloor Street. Sun access has been reduced to approximately two to three hours over most of the park between the spring and fall equinox. Already approved proposed development, adjacent to the park along Bloor, will eliminate the majority of the remaining sun access at the fall equinox. As a result, Cumberland Park should have no additional net increase in shading on the park area.

2. Devonian Park

This park now receives a generous amount of sunlight for a pocket park Approximately six hours of sun access are available over approximately 50 percent of the park site between the spring and fall equinox. In order to ensure the preservation of this sunlight condition, building heights adjacent to the park should be maintained at 18m. Since the buildings to the south are already 34m and 40m, they would be exempt. But properties to the east, now 14m and 17m, should be held to 18m. Development to the west of the park across Victoria Street should be held to 12m to ensure no loss of afternoon sun. The surrounding area is presently zoned at a height of 46m, and this height appears to not be in conflict with sunlight protection of the park.

3. Maple Leaf Quay

Presently this park receives plenty of sun access year-round; however, as development of the adjacent sites and of Harbourfront continues, the duration of sun access will be reduced. Approved developments should be exempted, but no additional shading should be permitted.

Plazas and Squares

These spaces are often associated with the city's major public institutions, such as City Hall at Nathan Phillips Square, or in association with major private buildings, as is the case with Trinity Square. The type is often characterized by areas with more hard surface than green, as found in College Park or Trinity Square. For the most part they are urban in character, related to major streets, and heavily used on a day-to-day basis. Such spaces are often primary locations for organized gatherings and ceremonial activities. Since these spaces are associated with public life within the city and strong architectural expression, they should receive sunlight during high-use times, specifically around lunchtime. Existing and potential plazas and squares studied include Dundas Square, Court House Square, Nathan Phillips Square, Trinity Square, and College Park.

Solar Access Standards

Because of their important contribution to public life:

All plazas and squares should have sun access at any time from one-and-a-half hours after sunrise to one-and-a-half hours before sunset (D.S.T.) from the spring to the fall equinox.

Where the plaza or square is to be located within high-density urban development, sun access should not be less than six hours from 10:18 a.m. (D.S.T.) to 4:18 p.m. (D.S.T.) from the spring to the fall equinox. For Plazas and Squares not studied in this report we recommend individual studies be undertaken for each plaza or square so that local conditions and programs can be taken into consideration.

SPECIFIC RECOMMENDATIONS:

1. College Park

College Park receives eight hours of sun access throughout the majority of the site. As development continues, some of this access will be eroded. Development should conform to a height limit of 18m on properties abutting the Park. Above this height, the heights of buildings within 300m distance from the Park will follow a cut-off plane that does not permit shading of the park in excess of the shadow already cast by the permitted building height of 18m. Existing buildings that exceed the height limit are exempt.

2. Trinity Square

This open space has approximately a five-hour sun access window. This is one hour less than the standard would recommend. Therefore, height limits should be set to avoid any net increase of shadowed areas from the present condition.

3. Nathan Phillips Square

Many parts of Nathan Phillips Square receive six hours of sun access at the the fall equinox. Ideally, since Nathan Phillips Square is the most important civic plaza in the central area, it should receive sunlight in accordance with the standard of sun access from one and-a-half hours after sunrise to one-and-a-half hours before sunset (D.S.T.) from the spring to the fall equinox. Since these ideal conditions do not exist, zoning heights in the vicinity of Nathan Phillips Square should be set to avoid any net increase in shading.

4. Court House Square

Court House square has extremely restricted sun access with an average of about one to two hours. This space should be designated as no net increase in shading.

5. Dundas Square

This space is proposed for possible future development as an inner-city square. At present, it receives an average of four hours of sun access. Building height in the vicinity of Dundas Square should be set to provide a minimum of three hours of sunlight.

Courtyards

Typically, such spaces are on private land and surrounded by buildings, yet are accessible by the public. Their small size and adjacency to buildings makes solar access problematic. They are especially important spaces for lunchtime use by employees of the surrounding buildings and by the general public. Solar access at lunch time is critical for providing human comfort. Surrounding development should be carefully arranged and developed to ensure protection of the small solar window that corresponds with this time. An example of a courtyard studied is Commerce Court.

Solar Access Standards

It is often difficult to provide solar access to courtyards, due to their size and degree of enclosure on all sides. Most courtyards, however, are capable of receiving some solar access in the summer and shoulder seasons.

Courtyards should have at least three hours of sun access from 11:18 a.m. (D.S.T.) to 2:18 p.m. (D.S.T.) between the spring and the fall equinox.

SPECIFIC RECOMMENDATIONS:

1. Commerce Court

Commerce Court receives on average two to three hours of sunlight. Unfortunately it seems that some of this sunlight is being eroded by larger buildings being constructed in the area. Future building shall result in no net increase of shadowing.

Forecourts

In the design of major developments or institutional buildings, there is often the opportunity and desire to create a larger open space associated with the entrance of a building or group of buildings. Such areas range in size from standard setbacks to more significant public open space allowing for a variety of passive uses. These spaces are usually urban in character, as in the forecourt to the Mowat Block on Bay Street, but are sometimes designed primarily as green spaces, such as the one adjacent to the Metropolitan United Church. Solar access to these spaces is heavily dependent on their size, location and orientation to the street. Solar considerations should begin with consideration of street standards ensuring optimum sun access to the space. The surrounding form of development should be designed to allow additional access. Forecourts include the Mowat Block Forecourt (Corner of Bay-Wellesley, North East side) and the Metropolitan United Church Grounds.

Solar Access Standards

It is difficult to set standards for forcourts, due to the variability of size and location on a street. Each particular application and circumstance should be studied individually.

In optimum locations, forecourts should receive six hours of sun access from 10:18 a.m. to 4:18 p.m. (D.S.T.) from the spring to the fall equinox.

Forecourts should not receive less than three hours of sun access if possible during lunch time.

SPECIFIC RECOMMENDATIONS:

1. Mowat Block Forecourt (Corner of Bay-Wellesley, North East side).

The Mowat Block receives an average of three hours of sun access over approximately 50 percent of the site, although primarily in the morning from 10:18 a.m. until noon. The site meets the standard of three hours of sun access. Existing height zoning on Bay Street of 30m would protect the site in the future.

2. Metropolitan United Church Grounds

This site has excellent sun access for a forecourt situation with approximately 5 hours' sun access at the perimeters. In fact, it is perceived by many to be a small park. In any case, the existing sun access should be maintained. The implications for height restrictions would be to limit the height for properties across the streets, the following heights should be permitted: 12m to the east, 16m to the south, and 18m to the west. Above these levels, the heights of buildings within shading distance from the Park will follow a cut-off plane that does not permit shading of the park in excess of the shadow already cast by the 12m, 16m, and 18m building height. Existing buildings would be exempt.

Urban Gardens

Like pocket parks, these are small, specialized spaces that are built in support of horticultural displays or historic buildings in addition to facilitating specific activities like viewing of sculpture. Their specific climatic requirements will be dependent on program and times of highest use. An example of an urban garden studied is Osgoode Garden.

Solar Access Standards

Generally, because of the horticultural importance of these gardens:

Urban Gardens should have sun access from one-and-a-half hours after sunrise to one-and-a-half hours before sunset (D.S.T.) from the spring to the fall equinox.

SPECIFIC RECOMMENDATIONS:

1. Osgoode Gardens

On average, Osgoode Gardens receives eight hours of sun access. In order to preserve this condition, the sunlight standard should permit building up to a height of 12m on properties abutting the Garden. On properties across the street on Queen Street and University Avenue, the rules pertaining to street windows of sunlight access could be applied. This would limit development of new properties west on University and south on Queen from 46m to 30m in height, respectively. Above these designated levels, heights of buildings within shading distance of the Garden will follow a cut-off plane that does not permit shading of the park in excess of the shadow already cast by the permitted building heights. Existing buildings that exceed the height limit are exempt.

6.2.3 Implementation of Sun Access to Publicly Accessible Open Spaces in the Central Area

The objective to guarantee sunlight for open spaces during those times of day and year when most needed for comfort of pedestrians can be achieved both through performance standards and through zoning height limits.

In order to implement sun access standards for open spaces, this study recommends the use of the city's zoning power to set height limit to provide sun access to all publicly accessible open spaces at those times of day and year when most needed for the comfort of pedestrians and open space users.

Such provisions are consistent with the regulatory power of city government, which is responsible for ensuring the health, safety, and well-being of its citizens. This policing power is used to avoid a nuisance that would occur if the city would not prohibit the shading of open spaces by future development. Specifically, to implement sun access for publicly accessible open spaces, the zoning height limits in the vicinity of open spaces would be set to prohibit the shading of open space properties.

In the following section, we demonstrate how the city could set the zoning height limits for a total of seven open spaces in the Central Area. The maps on the following pages illustrate "solar fans," which are sun access easements designed specifically for each open space.

This report recommends that all public and publicly accessible open spaces should be mapped using this methodology.

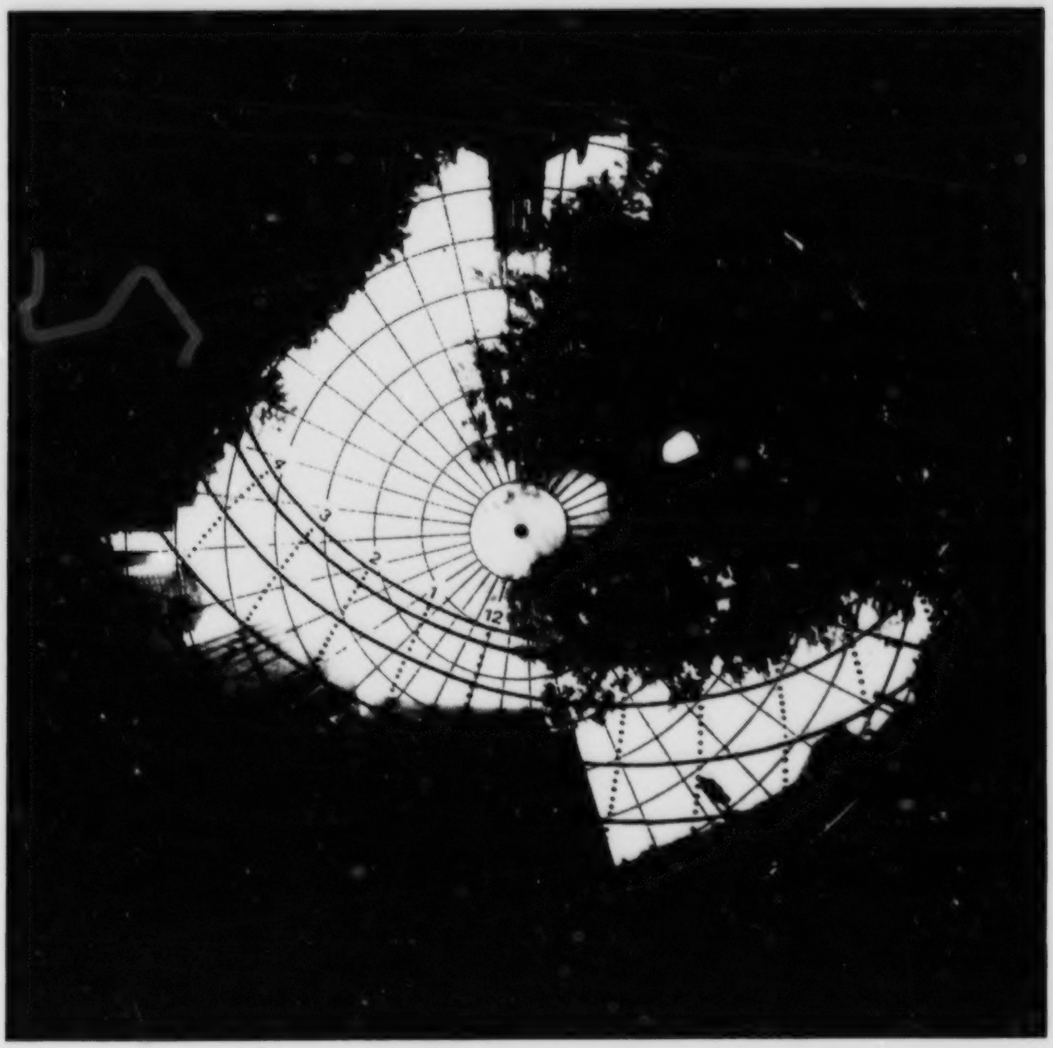
It is the recommendation of this report to apply sun access standards equally to public open spaces and to private open spaces that are publicly accessable.

In this process, care should be taken to analyze each individual open space so that local conditions and programs can be taken into account when height limits are considered.

6.2.4 The Use of Performance Standards to Implement Sun Access to Open Spaces.

It is possible to use performance standards to implement sun access in open spaces. Like sun access to streets, the implementation of such controls could only be possible if the City of Toronto were to have the capability to verify the acccuracy of all shadow studies prepared for proposed development, including the shadows cast by existing structures. Members of our team have experience with the development of a computerized three-dimensional data base and with the development of software suitable for accurate shadow analysis, consistent with standards described in this report. An accuracy criterion of +/- 10cm would be necessary for all vertical and horizontal input dimensions in order to produce shadow predictions with an accuracy of +/- 1.5m. This accuracy can be achieved, but would require a far greater accuracy and precision than currently available in the existing Toronto database (see 6.1.3, Implementation of sun access to streets).

SOLAR FANS



Fisheye View of Sky above the Metropolitan United Church Grounds taken midpoint between Bond and Church Streets near the Queen Street sidewalk

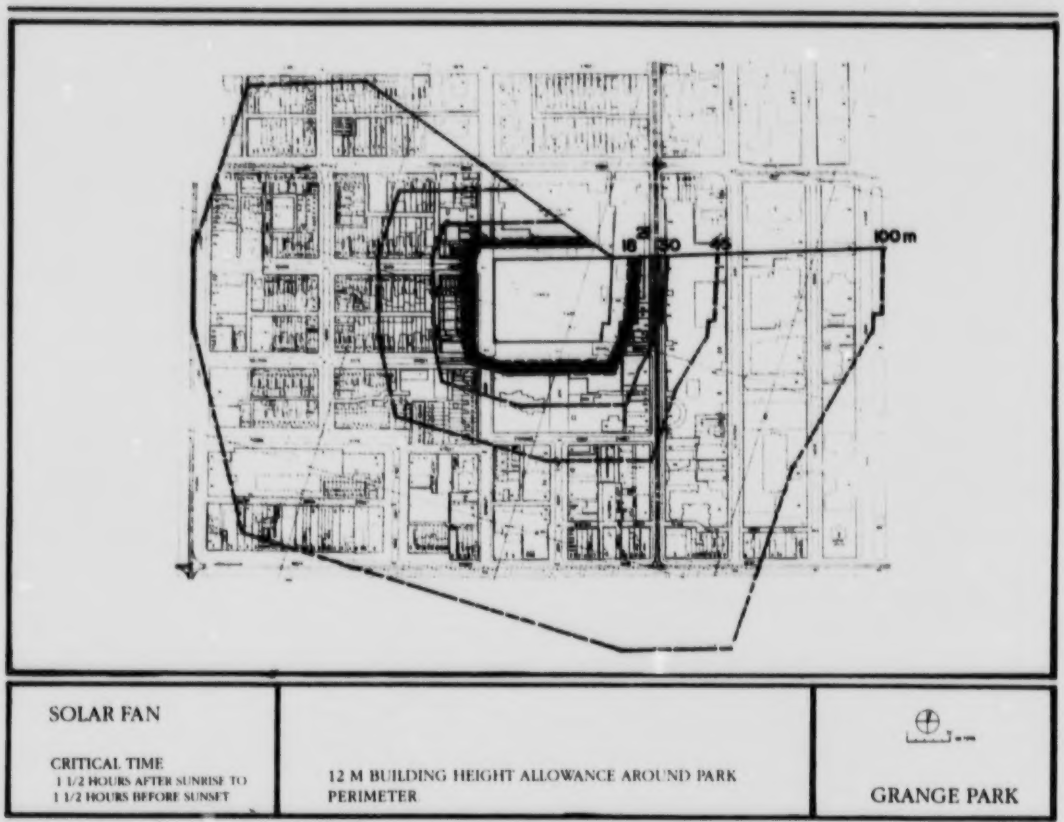
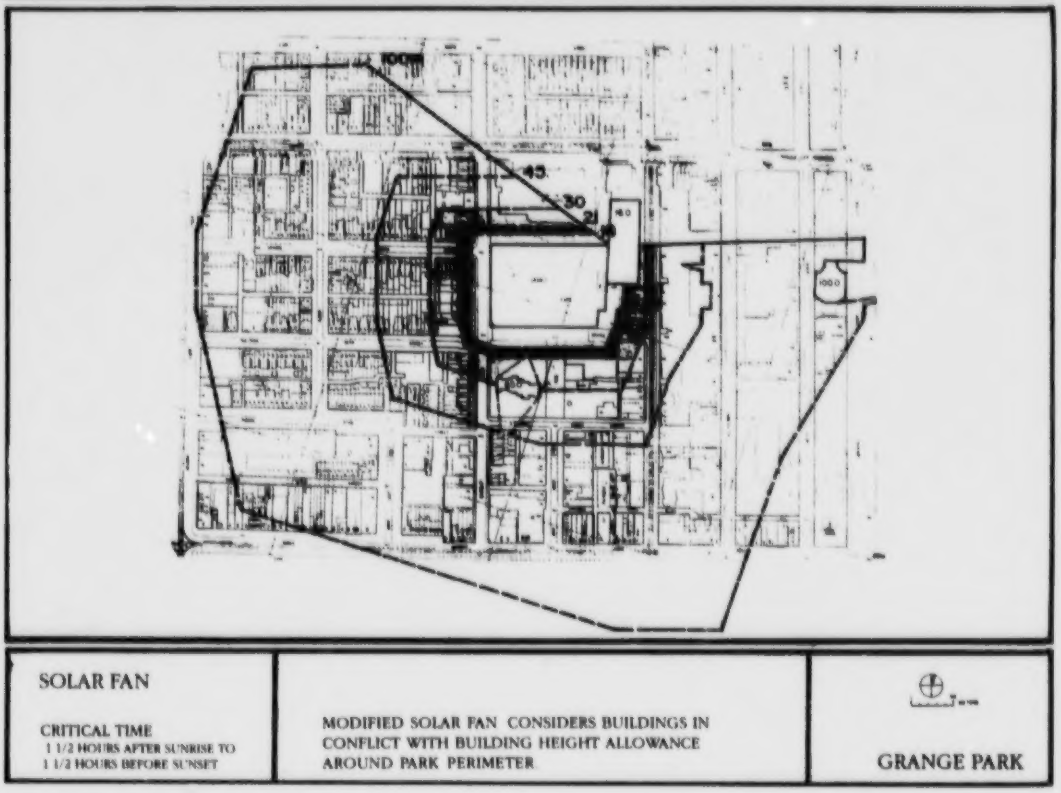

18
21
30
45
100m
SOLAR FAN
CRITICAL TIME
1 1/2 HOURS AFTER SUNRISE TO
1 1/2 HOURS BEFORE SUNSET
12 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
GRANGE PARK

Fig. 6.4 Solar Fan for Grange Park

For example, the solar fan for Grange Park is designed to prohibit any additional shading of the park property between one-and-one-half hours after sunrise to one-and-one-half hour before sunset for all months of the year. The first map, Fig. 6.4, shows how the solar fan defines building heights in the vicinity of Grange Park. Solar fans consist of sun access planes that slope away from the property line of an open space up to the location of the sun. Given the frequently rectangular shape of open space properties, such a sloping plane is struck from each side of the rectangle. The result is a set of sun access planes that take the shape of a fan. In the case of Grange Park, the bottom of each sloping plane is set at a height of 12m, along the property line of the Park, permitting shadows created by building up to 12m in height. As the sun access plane slopes upwards from this height of 12m, it defines allowable building heights on properties in the neighborhood surrounding Grange Park.

The map in Fig. 6.5 shows how the slope of the sun access planes is altered by those existing buildings that penetrate through the solar fan. This last map needs to be compared with the zoning height map (Fig. 6.6) of the area. Such a comparison would indicate whether conflict exists between the current zoning height and sun access planes to the north, west, south, or east of the park. In the case of Grange Park, for all properties, the current zoning heights are more restrictive than allowable building heights set by the solar fan. With the exception of the two highrise buildings shown in Fig. 6.5, existing building heights conform to the sun access standard recommended for this park. We have prepared similar maps for the following open spaces: Osgoode Mall, Fig. 6.7-6.9, Devonian Square, Fig. 6.10-6.12, Trinity Square, Fig. 6.13-6.15, Mowat Block, Fig. 6.16-6.18, Osgoode Gardens, Fig. 6.19-6.21, and, Commerce Court, Fig.6.22-6.24


40
30
21
1000

SOLAR FAN

CRITICAL TIME
1 1/2 HOURS AFTER SUNRISE TO
1 1/2 HOURS BEFORE SUNSET

MODIFIED SOLAR FAN CONSIDERS BUILDINGS IN CONFLICT WITH BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER

GRANGE PARK

Fig. 6.5 Modified Solar Fan for Grange Park

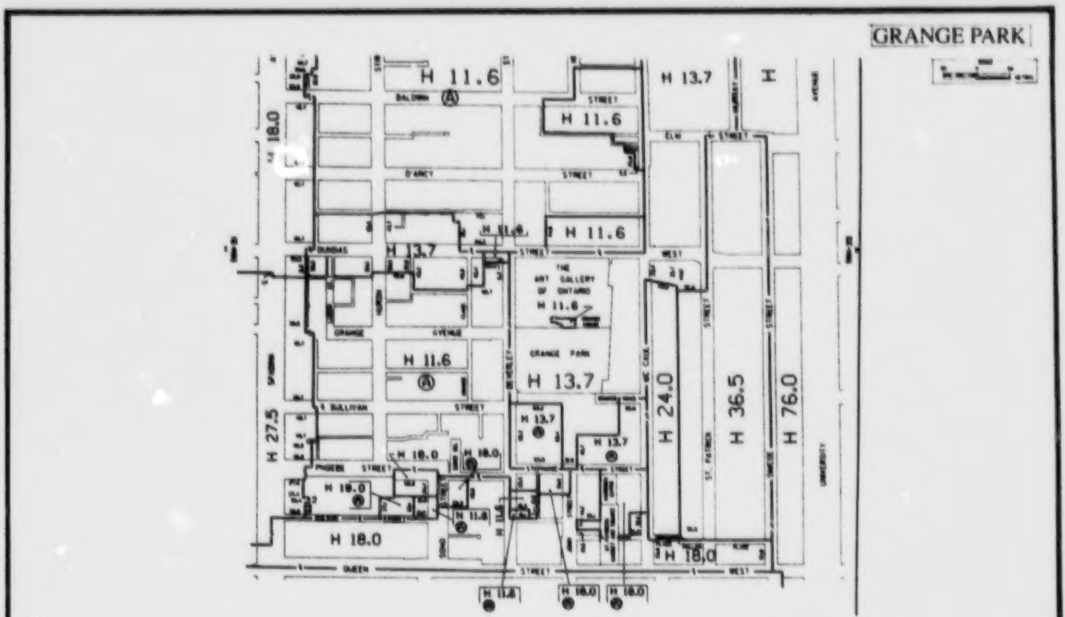

GRANGE PARK
H 11.6
H 13.7
H 11.6
H 18.0
H 11.6
H 13.7
THE ART GALLERY OF ONTARIO
H 11.6
GRANGE PARK
H 11.6
H 13.7
H 24.0
H 36.5
H 76.0
H 27.5
H 13.7
H 13.7
H 18.0
H 18.0
H 18.0
H 18.0
H 18.0
H 11.6
H 11.6
H 18.0
H 18.0
DUNDAS
D'ARCY
STREET
STREET
ELM
ORANGE
AVENUE
SULLIVAN
STREET
PHOEBE STREET
QUEEN
STREET
WEST
ST. PATRICK
SIMCOE
UNIVERSITY
AVENUE
BEVERLEY
MC CAUL

Fig. 6.6 Grange Park Zoning Height Map

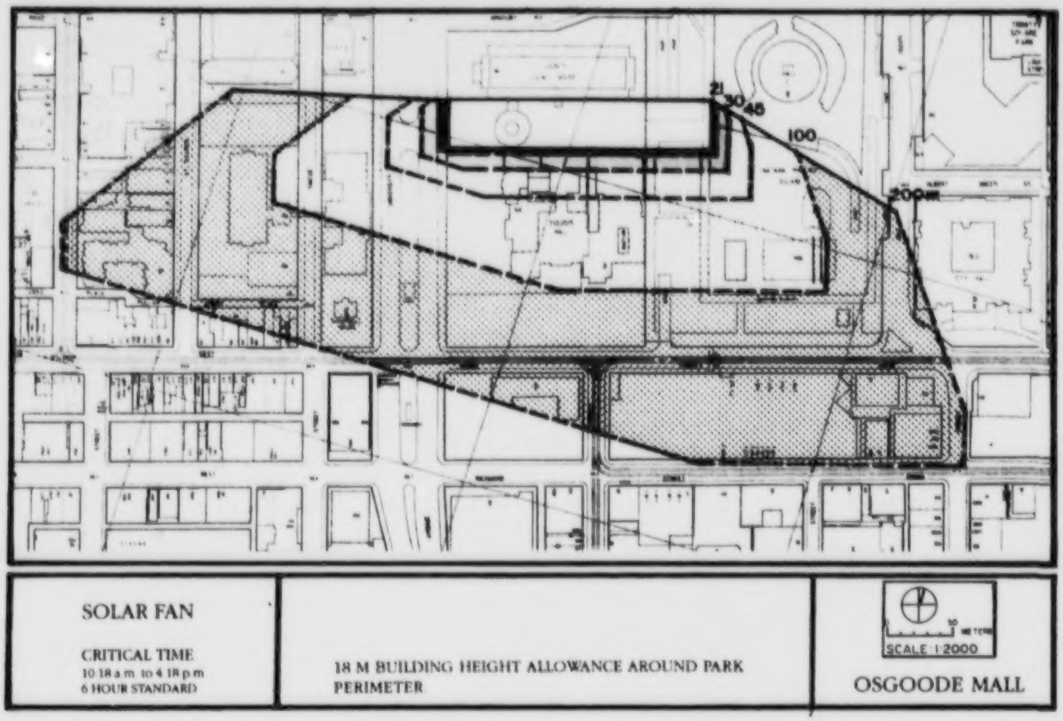

21
30
45
100
200m
SOLAR FAN
CRITICAL TIME
10 18 a.m. to 4 18 p.m.
6 HOUR STANDARD
18 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
0
10
METERS
SCALE 1:2000
OSGOODE MALL

Fig. 6.7 Solar Fan for Osgoode Mall

The current zoning height limits are not in conflict with the exception of the section to the southeast at the eastern end of Osgoode Mall.

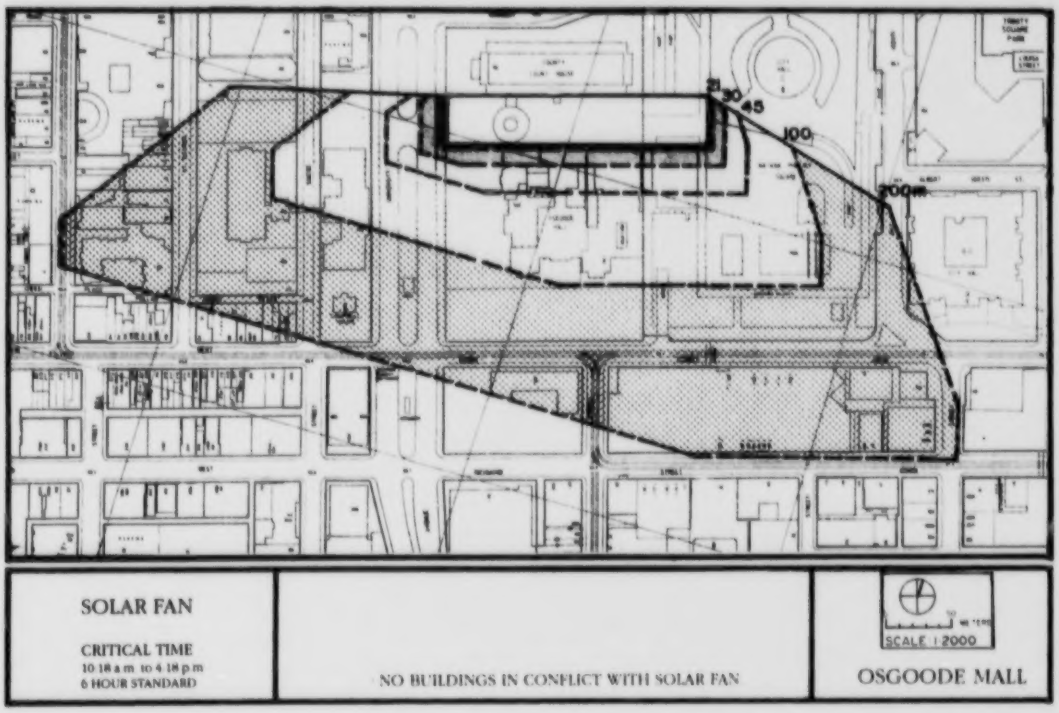

21
30
45
100
200m
SOLAR FAN
CRITICAL TIME
10:18 a.m. to 4:18 p.m.
6 HOUR STANDARD
NO BUILDINGS IN CONFLICT WITH SOLAR FAN
SCALE 1:2000
OSGOODE MALL

Fig. 6.8 Modified Solar Fan for Osgoode Mall

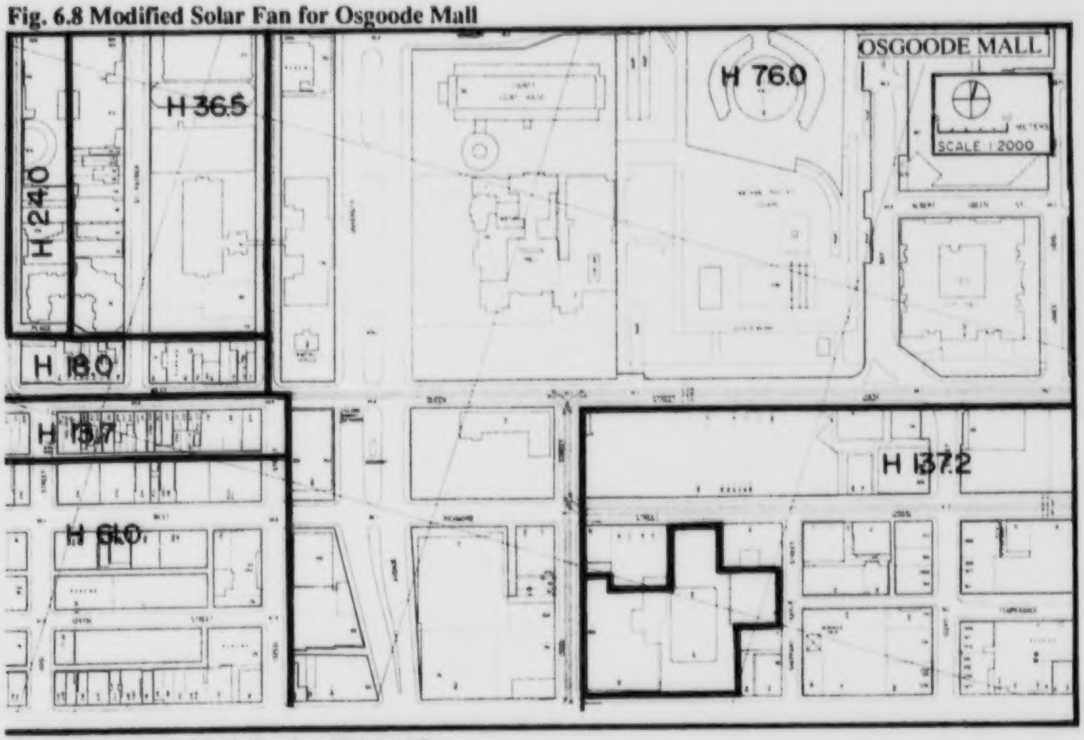

OSGOODE MALL
SCALE 1:2000
H 76.0
H 36.5
H 24.0
H 18.0
H 15.7
H 61.0
H 137.2

Fig. 6.9 Osgoode Mall Zoning Height Map

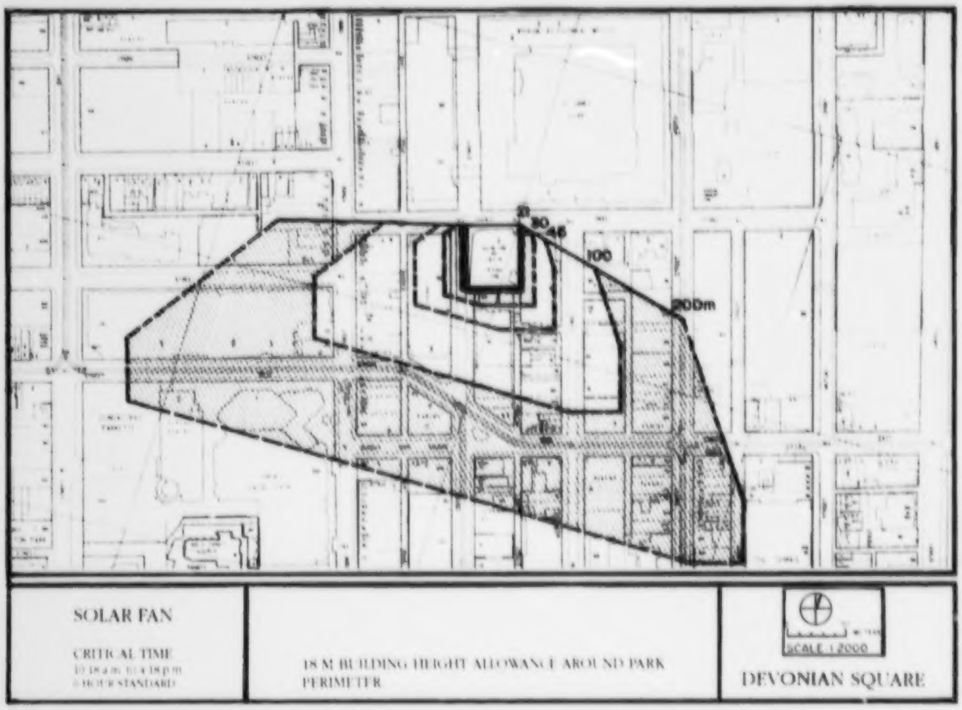

18
30
46
100
200m
SOLAR FAN
CRITICAL TIME
10:18 a.m. to 4:18 p.m.
6 HOUR STANDARD
18 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
SCALE 1:2000
DEVONIAN SQUARE

Fig. 6.10 Solar Fan for Devonian Square

The current zoning height limit of 46m to the east, south, and west of Devonian Square is in conflict with the allowable height limit permitted under the solar fan.

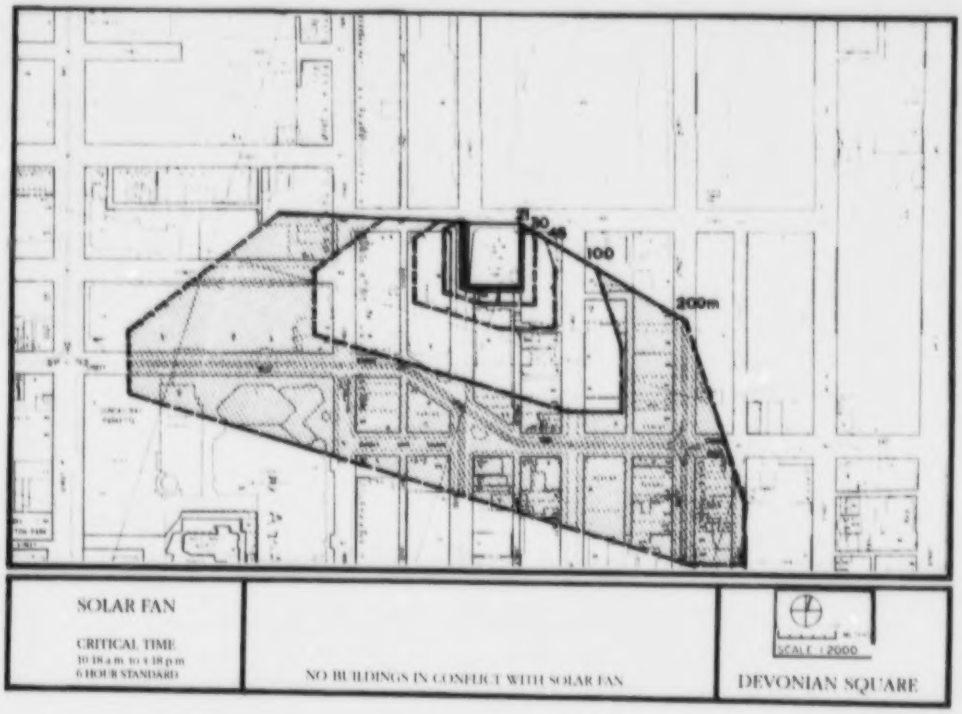

30
40
100
200m
SOLAR FAN
CRITICAL TIME
10:18 a.m. to 4:18 p.m.
6 HOUR STANDARD
NO BUILDINGS IN CONFLICT WITH SOLAR FAN
SCALE 1:2000
DEVONIAN SQUARE

Fig. 6.11 Modified Solar Fan for Devonian Square

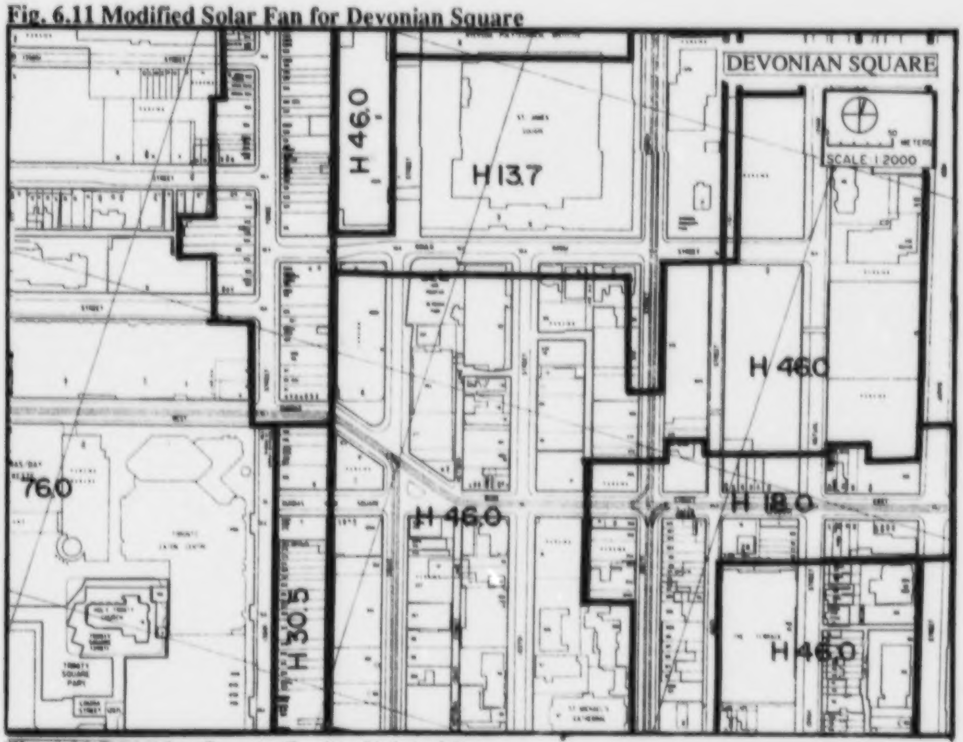

DEVONIAN SQUARE
SCALE 1:2000
H 46.0
H 13.7
H 46.0
76.0
H 46.0
H 18.0
H 30.5
H 46.0

Fig. 6.12 Devonian Square Zoning Height Map

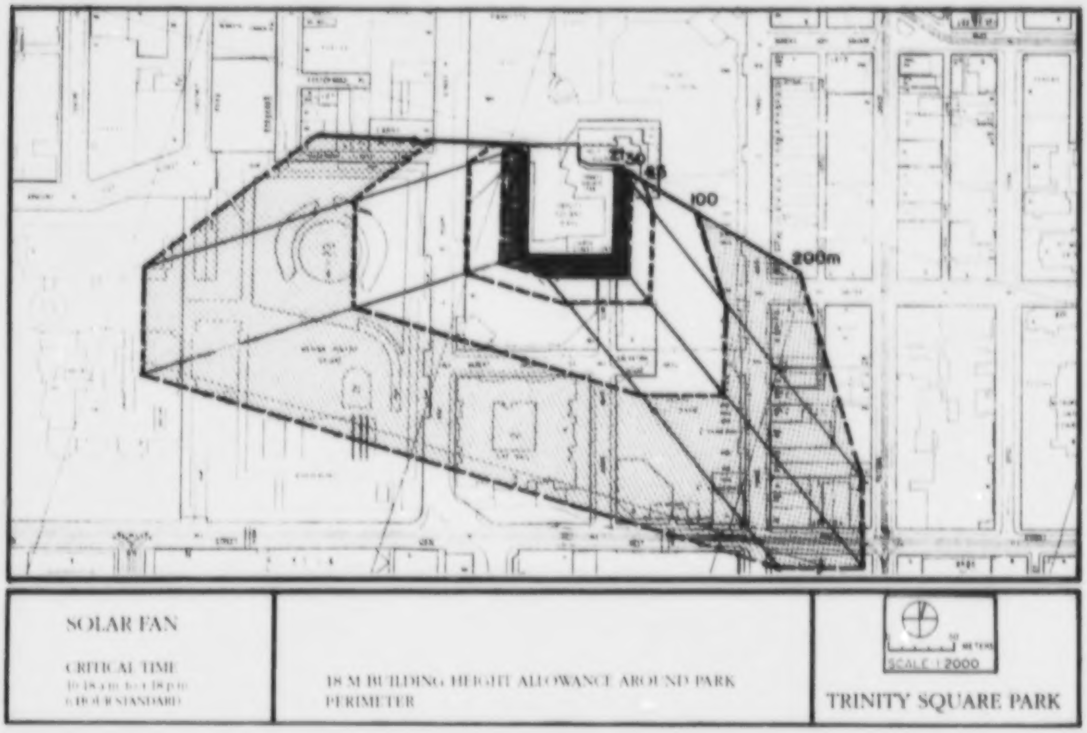

65
100
200m
SOLAR FAN
CRITICAL TIME
10:18 a.m. to 4:18 p.m.
6 HOUR STANDARD
18 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
METERS
SCALE 1:2000
TRINITY SQUARE PARK

Fig. 6.13 Solar Fan for Trinity Square Park

The current zoning height limits are not in conflict with the height limits under the solar fan.

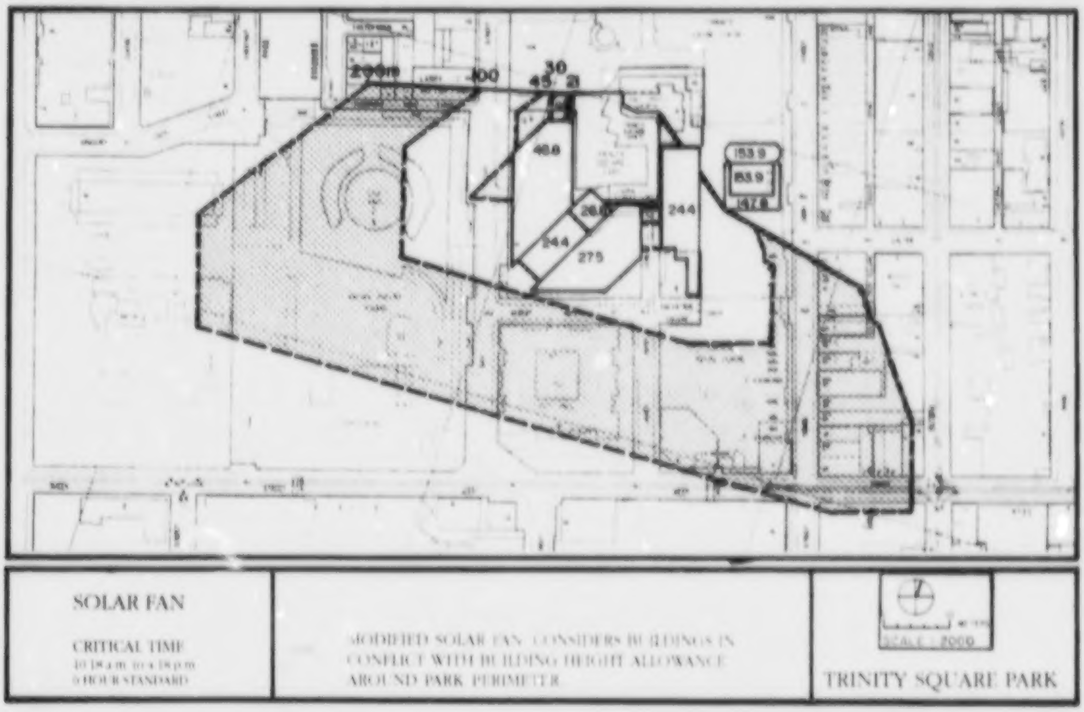

200m
100
30
45
21
48.8
153.9
153.9
147.8
244
26.0
244
275
SOLAR FAN
CRITICAL TIME
MODIFIED SOLAR FAN CONSIDERS BUILDINGS IN CONFLICT WITH BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
SCALE 1:2000
TRINITY SQUARE PARK

Fig. 6.14 Modified Solar Fan for Trinity Square Park

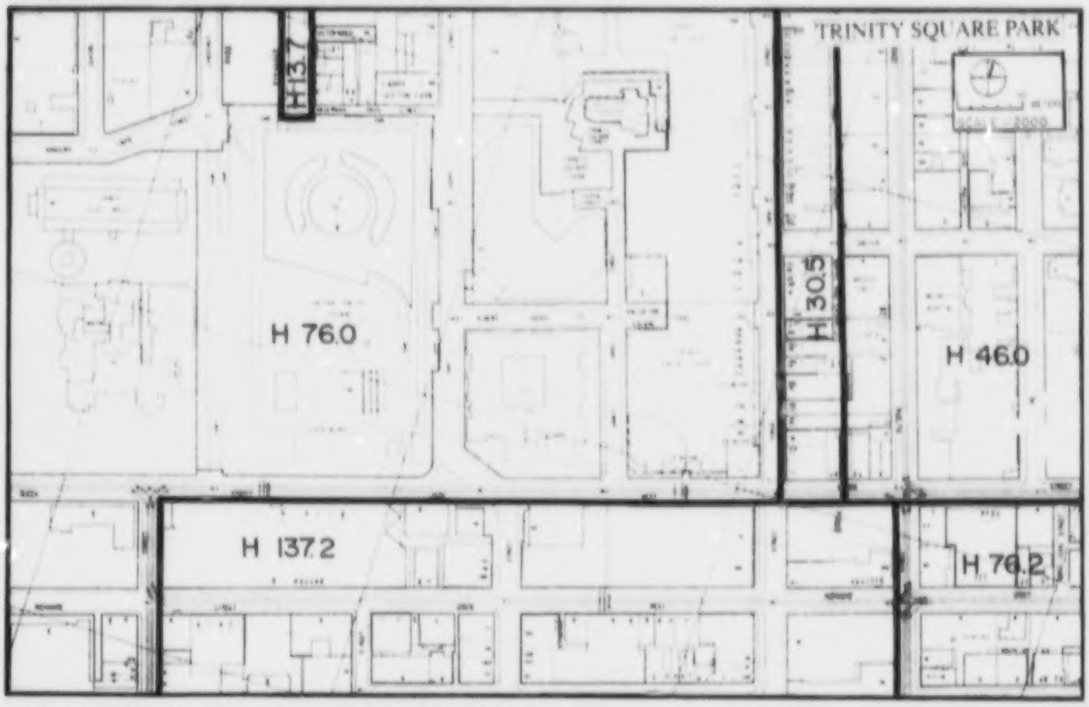

TRINITY SQUARE PARK
SCALE 1:2000
H 13.7
H 76.0
H 30.5
H 46.0
H 137.2
H 76.2

Fig. 6.15 Trinity Square Park Zoning Height Map

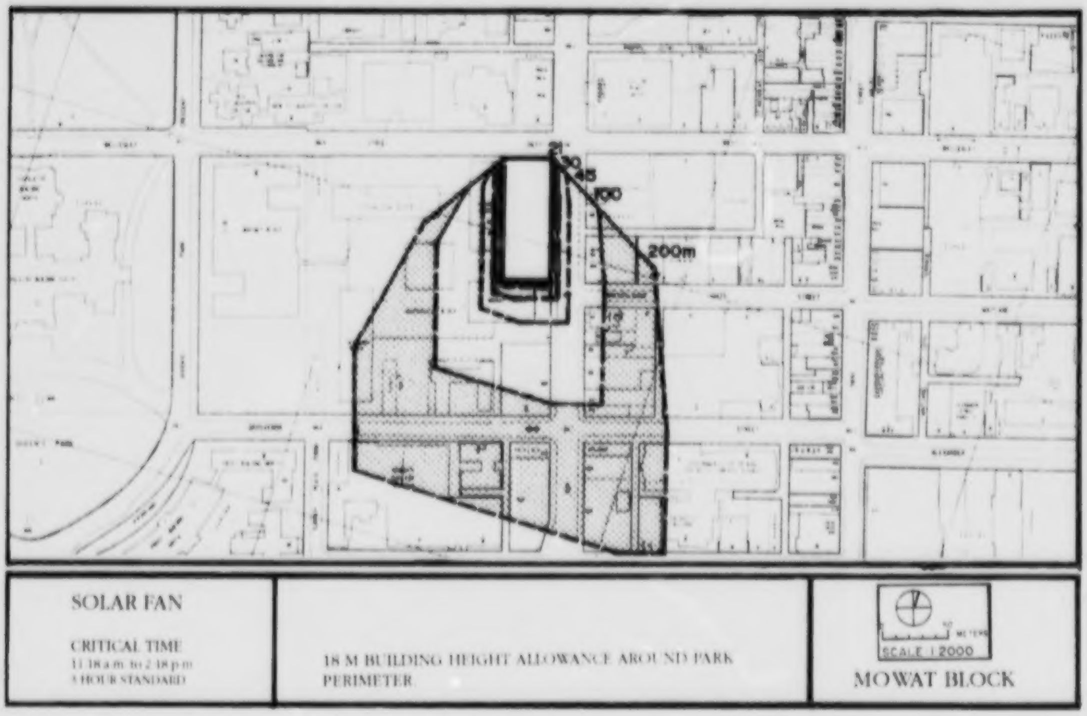

20
45
100
200m
SOLAR FAN
CRITICAL TIME
11:18 a.m. to 2:18 p.m.
3 HOUR STANDARD
18 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
METERS
SCALE 1:2000
MOWAT BLOCK

Fig. 6.16 Solar Fan for Mowat Block

The current zoning height limits are not in conflict with height limits under the solar fan.

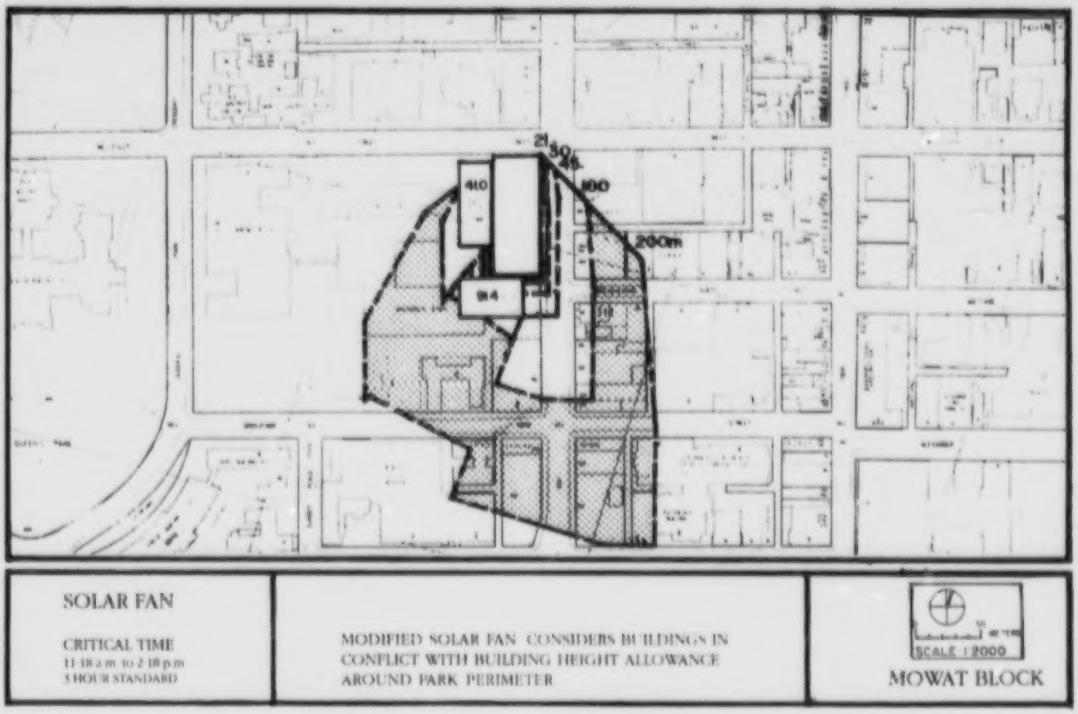

21
30
45
180
410
914
200m
SOLAR FAN
CRITICAL TIME
11:18 a.m. to 2:18 p.m.
3 HOUR STANDARD
MODIFIED SOLAR FAN CONSIDERS BUILDINGS IN CONFLICT WITH BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
50 METERS
SCALE 1:2000
MOWAT BLOCK

Fig. 6.17 Modified Solar Fan for Mowat Block

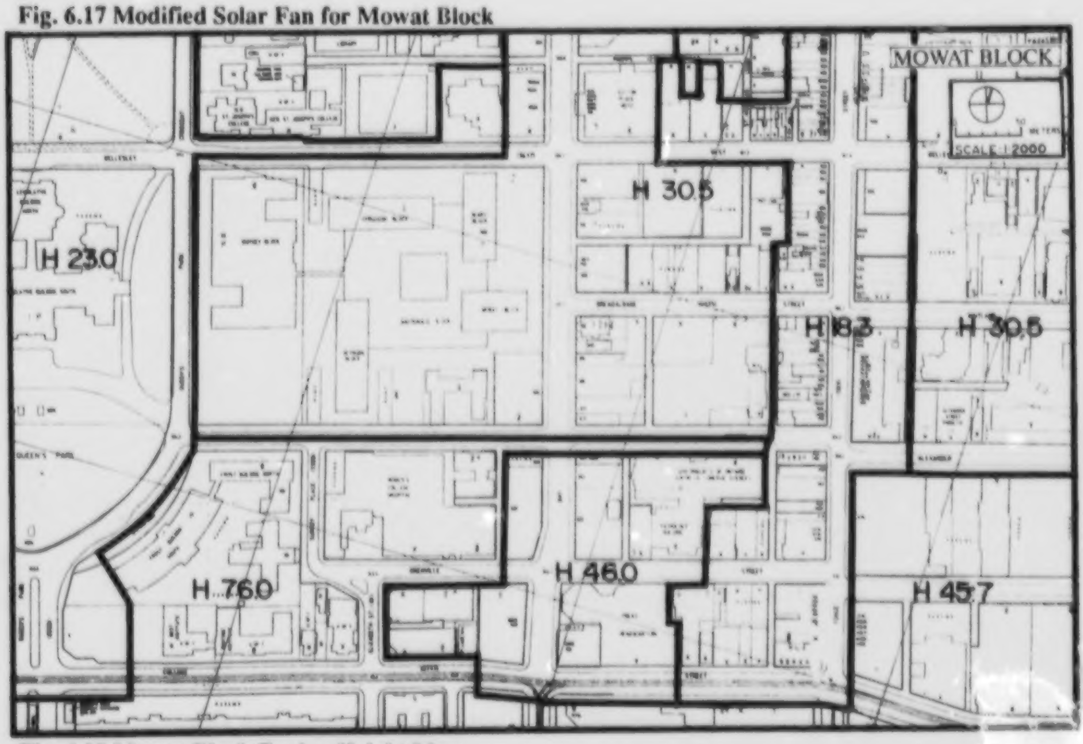

MOWAT BLOCK
50 METERS
SCALE 1:2000
H 30.5
H 23.0
H 18.3
H 30.5
H 76.0
H 46.0
H 45.7

Fig. 6.18 Mowat Block Zoning Height Map

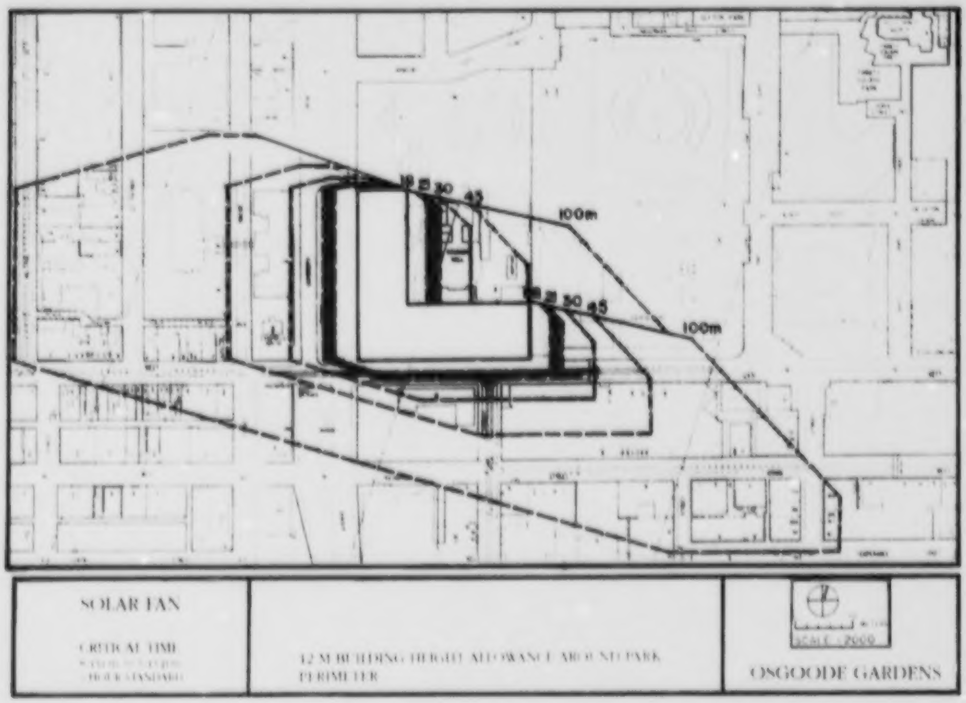

15
20
30
45
100m
15
20
30
45
100m
SOLAR FAN
CRITICAL TIME
12 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
SCALE 1:2000
OSGOODE GARDENS

Fig. 6.19 Solar Fan for Osgoode Gardens

The current zoning height limits to the east, south, and west of Osgoode Gardens are in conflict with the allowable height limits permitted under the solar fan.

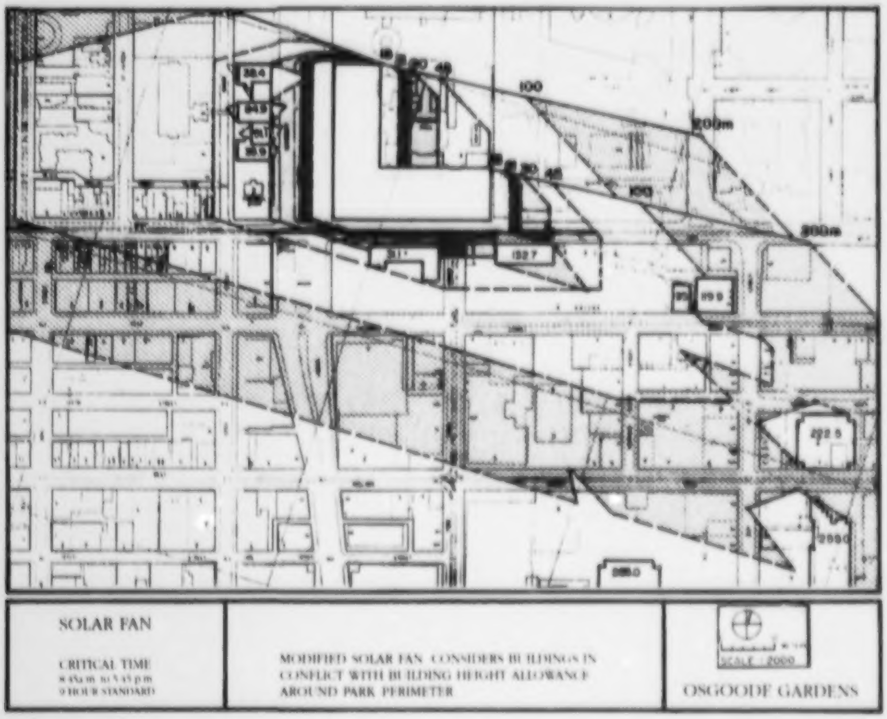

100
200m
150
300m
132.7
159
222.5
SOLAR FAN
CRITICAL TIME
8:45a.m. to 5:45 p.m.
9 HOUR STANDARD
MODIFIED SOLAR FAN CONSIDERS BUILDINGS IN CONFLICT WITH BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
SCALE 1:2000
OSGOODE GARDENS

Fig. 6.20 Modified Solar Fan for Osgoode Gardens

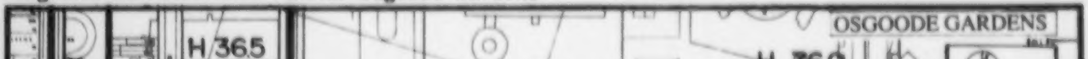

H 36.5
H 24.0
H 18.0
H 61.0
H 76.0
H 137.2
OSGOODE GARDENS
SCALE 1:2000

Fig. 6.21 Osgoode Gardens Zoning Height Map

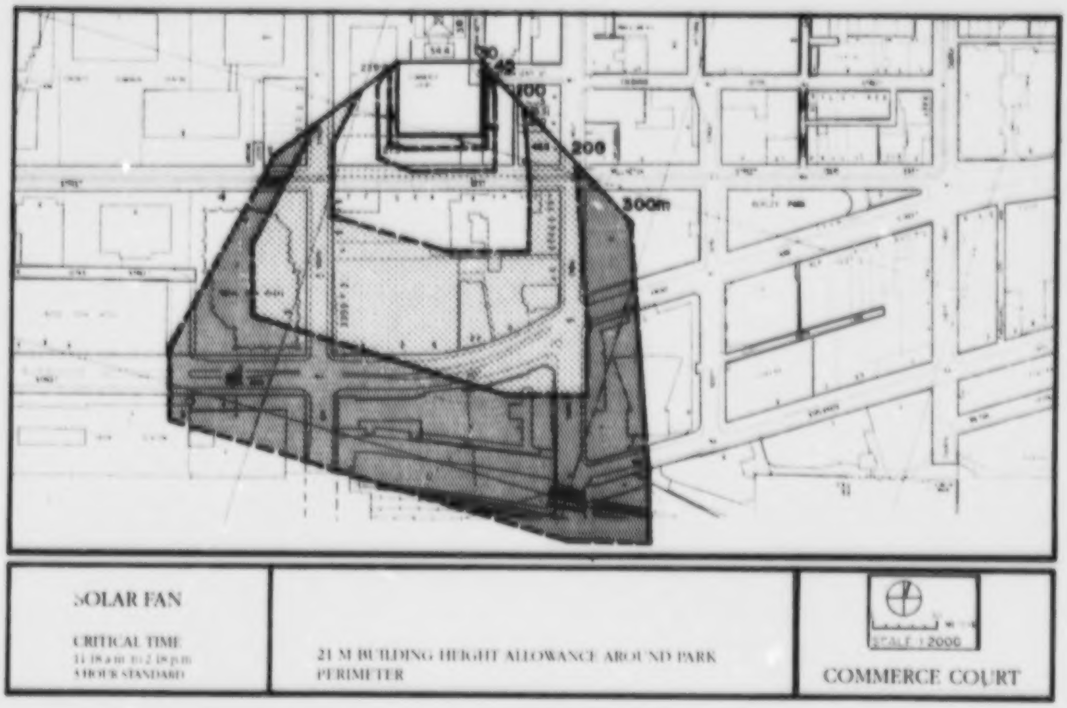

50
42
100
200
300m
SOLAR FAN
CRITICAL TIME
11:18 a.m. to 2:18 p.m.
3 HOUR STANDARD
21 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
SCALE 1:2000
COMMERCE COURT

Fig. 6.22 Solar Fan for Commerce Court

The current zoning height limits to the east, south, and west of Commerce Court are in conflict with the allowable height limits permitted under the solar fan.

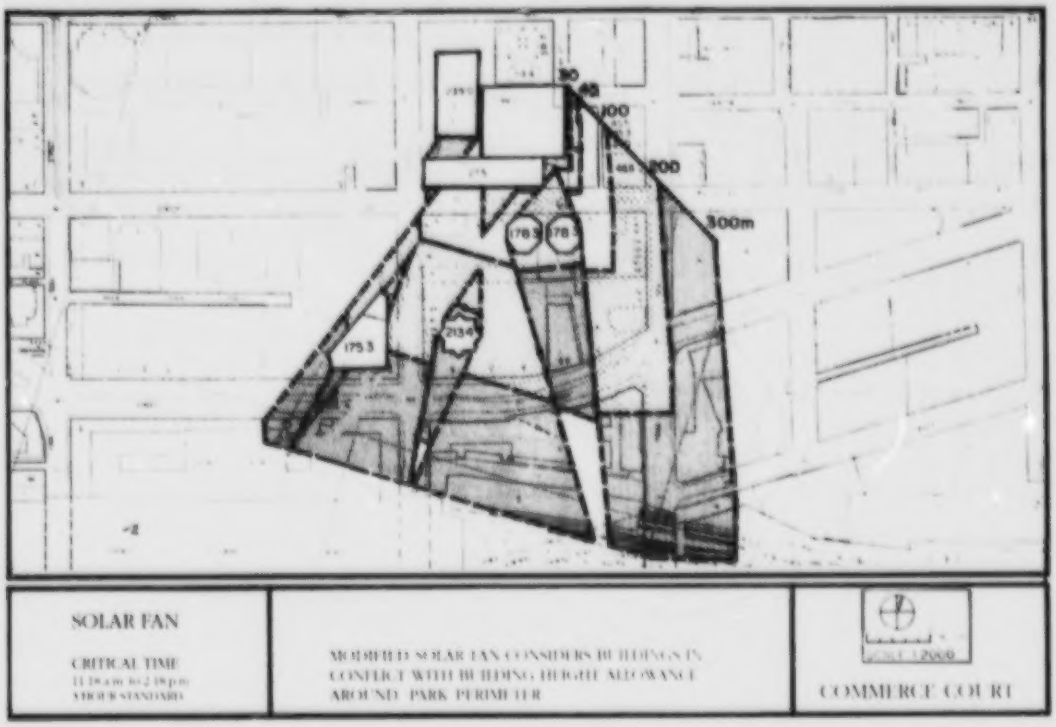

30
40
100
200
300m
1753
2134
1785
1785
SOLAR FAN
CRITICAL TIME
11:18 a.m. to 2:18 p.m.
5 HOUR STANDARD
MODIFIED SOLAR FAN CONSIDERS BUILDINGS IN CONFLICT WITH BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER
SCALE 1:2000
COMMERCE COURT

Fig. 6.23 Modified Solar Fan for Commerce Court

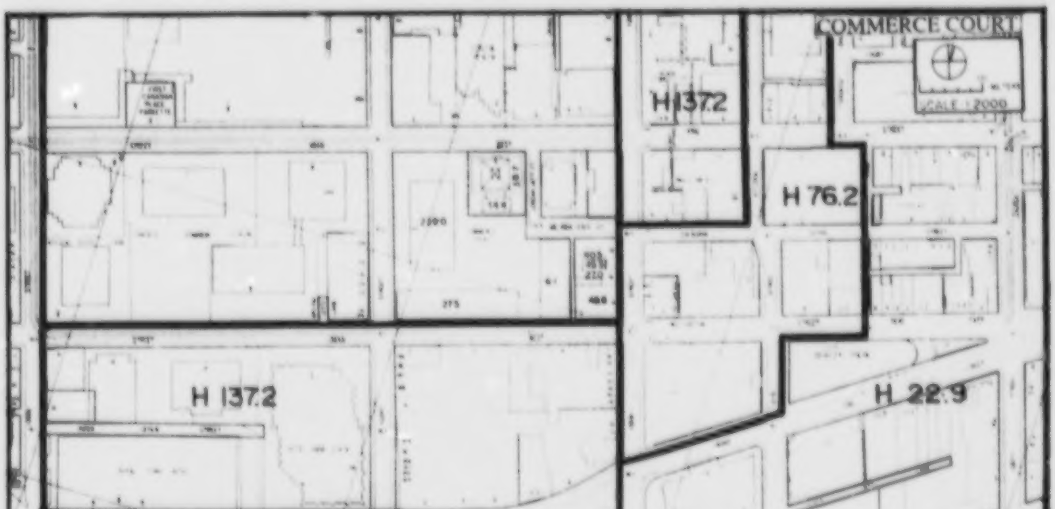

COMMERCE COURT
SCALE 1:2000
H137.2
H 76.2
H 137.2
H 22.9

Fig. 6.24 Commerce Court Zoning Height Map

6.3 Recommendations Regarding Development Standards for Protection from Adverse Wind Conditions

This study, and studies in other cities, confirm that abrupt changes in the height of buildings have a significant effect on wind velocities on adjacent streets and parks. In Toronto, this observation is particularly important along the lakefront, where an abruptly rising row of highrise apartment towers has increased wind velocities, especially on days when winds blow from the southwest and east.

Abruptly rising buildings are also concentrated along Bloor and Bay Streets. Once large buildings are constructed in an area where low buildings predominate, it is extremely difficult, if not impossible, to design buildings that mitigate the negative effect.

1. **This study recommends that the existing height zones of the Central Area should be reexamined with the purpose of avoiding height zone changes that exceed 100 percent of the height of the previous zone. Under existing zoning legislation, existing height zones frequently abut, resulting in abrupt height changes from one side of the street to the other or within one block. A city zoned to avoid drastic height changes would result in an urban form shaped like a gradually rising hill or ridge.**

2. **This study recommends that height zones should abut in the center of blocks, and not along streets.**

3. **This study recommends that the City of Toronto develop and implement a wind effects standard, or code, as discussed below:**

The wind code would be best developed through a consensus process involving City officials and the various wind researchers and consultants in the Toronto region. The code could apply all proposed projects that had the potential for wind problems, either through their height or their exposed location. Presumably the Department of Planning would be responsible for determining which projects are to be evaluated under the wind code.

The new code should be applied in the review of proposed buildings located on properties in height zones of 30m and highter. Here all building proposals should be subject to wind tunnel studies unless the consultants certify that the wind effect caused by a proposed building would be negligible.

Proposed buildings in height zones below 30m should be subject to wind tunnel testing if the height of the proposed structure exceeds the predominant building height of existing buildings in the vicinity of the proposed building by four floors, or by 10.5 m.

Project vicinity is defined as the area directly upwind from the project site in the directions of the predominant winds during fall, winter, and spring.

The wind effects standard should, at a minimum, assure that the mechanical effects of the wind are kept within acceptable limits. The mechanical effects include comfort and safety considerations.

Fig 6.25

It might be appropriate to have two velocity limits for comfort (e.g. hourly average velocities of 7 mph for seating areas and 11 mph for walking areas) and one for safety (e.g. 44 mph for a 3-second gust, exceeded some maximum number of times per year). Deciding on the exact values for these figures should be part of the development process, since opinions will differ on how a standard is best structured.

This recommended standard could be supplemented with a wind-chill equation to take partial account of the thermal influence of wind during cold periods. A number of such equations exist now, with fair agreement among them. To add this supplement in the standard would require that temperature be added to the wind weather database, an addition to what is required for mechanical-effects standards.

In the future, the standard could include a more comprehensive simulation of the effects of wind, sun, temperature, and humidity on thermal comfort, similar to the computer model that was used in this study. The results from this proposed thermal simulation would be combined in the standard with the mechanically-induced comfort and safety effects described above. The standard of compliance would then be based on the number of hours of comfort/safety and discomfort/hazard expected at street level during specified periods throughout the year. Such a simulation would require year-long sets of hourly weather observations typical of long-term (i.e. most likely future) climate, in addition to the summarized wind data required for the mechanical-effects standard.

This future comprehensive approach would require substantial development work before it could be written into a standard. The hourly weather datasets would need to be assembled and adjusted using a typical year procedure to represent the long-term past climate. The thermal model must be calibrated and validated for the Toronto population. Administrative decisions must be made, such as how to weight the comfort advantages of a scheme under summer conditions against disadvantages that it might create under winter conditions, or vice versa? These are issues that have not been addressed before in a standard. Researchers and practitioners understand and agree upon the criteria for acceptability of mechanical wind effects far more than for the newer study of thermal effects. On the other hand, there is interest being currently expressed by some Toronto-region wind consultants in developing such a thermal standard for several other cities in the Toronto area. The City of Toronto might be in a good position to participate in such development work, or at least develop its standard in such a way that the future possibility of a thermal standard is not excluded.

There is a present need for a mechanical-effects wind standard, even without the thermal standard. The work needed to develop the mechanical standard would be directly transferable to the thermal standard if and when the thermal standard would be developed. The model includes the following:

1. A standard method should be used to define the wind's boundary layer in the various parts of the city. This boundary layer could be matched by any consultant performing wind studies for compliance to the wind standard.

The required turbulence characteristics of the boundary layer should also be specified.

2. Weather data sets should be assembled and standardized as the official sets for tests in specific areas. A qualified consultant could examine the available records for the city and its environs and produce statistics for wind and temperature during specified periods of day throughout each month of a typical year.

3. Standards should specify wind velocity limits (acceptability criteria) for safety and various types of comfort such as sitting and walking These limits would preferably be accompanied by the percentage of time that each limit is not to be exceeded, during specific periods of the day and seasons of the year. The Berkeley team agrees with some of the local wind consultants that exceedence criteria is best expressed in terms of percentage of time rather than in terms of recurrence intervals. The percentage of time results are then more easily and intuitively understood by the layman.

4. The procedure for proving a project's compliance to the standard should be clearly specified. For this reason, it would be useful to develop a standard format for the consultants' reports.

5. Review of the enabling legislation should lead to an appropriate implementation method for the wind code.

7. IMPLEMENTATION

Future Research Needs to Implement the Recommendation of this Report.

A thorough revision of Central Area zoning is required for the implementation of this report's recommendation. Zoning heights in Toronto's Central area need to be analyzed, in many cases revised, and made compatible with density controls.

Urban design studies of critical areas and typical city blocks will be a prerequisite for such revisions. This section of the report includes examples that illustrate how such urban design studies could lead to informed decisions regarding building heights, setbacks, configurations, and density controls.

This study does not recommend the use of performance standards for the implementation of sun access standards.

If the City were to use performance standards, the future analytical needs of the Department of Planning and Development would be significant and costly (see Sections 6.1.3 and 6.2.4). The existing computer modeling capability of the City is sufficient for the necessary revisions to height and density controls. Both existing scale models and computer models are sufficient as a visualization tool in the analysis of critical areas and typical city blocks.

A performance standard will be necessary to implement a newly established wind code. Height limits and controls regarding setbacks alone will not prevent building induced wind velocities that are adverse to pedestrians and open space uses. The establishment of such a new wind code should be made with the cooperation of local consultants or academic groups who would be qualified to perform wind tunnel testing. The City of Toronto will have to set aside funds for acquisition of an Official Standard Weather Dataset to be used by all consultants in the testing. We recommend that one of the local consultants be given the task to compile this data.

Finally, the implementation of this report requires urban design studies of typical streets in the Central Area. These studies include work on a street classification system and detailed recommendations with regard to street trees and sidewalk design.

Urban Design Studies of Selected City Blocks.

The following section includes examples of urban design studies that would be required prior to revisions of height and density controls.

North Midtown-Yorkville
This block was chosen as an example because in this area between Cumberland and Scollard Streets, future planning controls would need to encourage an important transition between the high-density commercial development along Bloor Street to the low-density residential scale of the neighborhoods north of Scollard Street. Figs. 7.1 and 7.2 are centered on the block between Scollard and Yorkville Avenue, between Bay and Yonge Streets.

The southeastern part of this block is currently zoned for building height up to 14m, the northeastern portion permits buildings up to 30.5m. The 14m zoning height along Yonge Street and half the length of Yorkville Avenue is lower than the building heights possible under sun

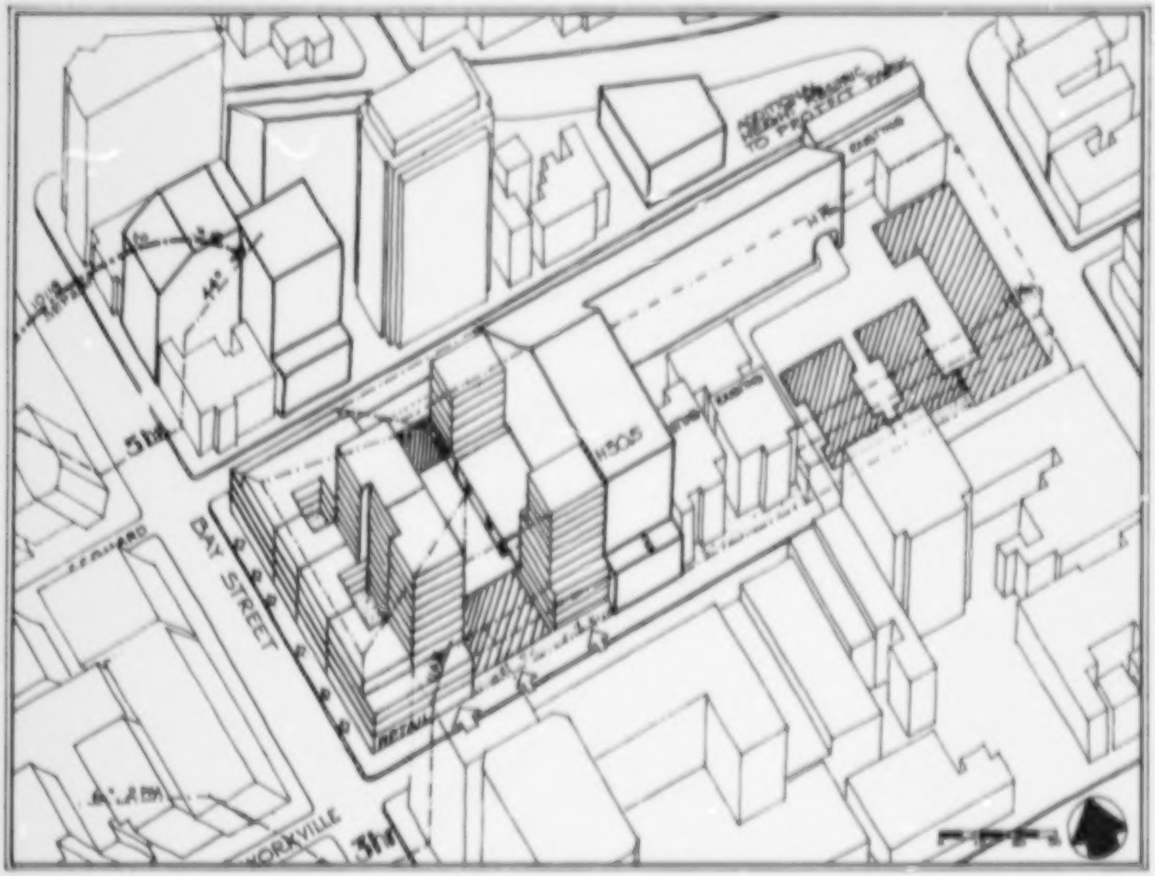


Fig 7.1 North Midtown-Yorkville Area Comfort Controls Combined with Existing Height Limits

access controls. Therefore, sun access controls would not take effect. The future height of buildings along Bay Street and the entire length of Scollard will be constrained by sun access controls. According to our recommendations this northern section of Bay Street should receive sunlight for five hours in September. Along Scollard Street, sun access controls would prevent future building from reaching the 30.5m height limit. The maximum density shown here would be four times the coverage in the area, limited to 30m, and two times coverage in the area, with a 14m height limit.

Fig. 7.2 shows how the intended transition between high density and low density might be achieved. The height limit would be set to 16m for much of the entire block. Only along Bay Street would building heights of up to 21m be permitted. The density would result in a coverage of 1:3.0 for the entire block. Future building would be more compatible with the built form of Yorkville.

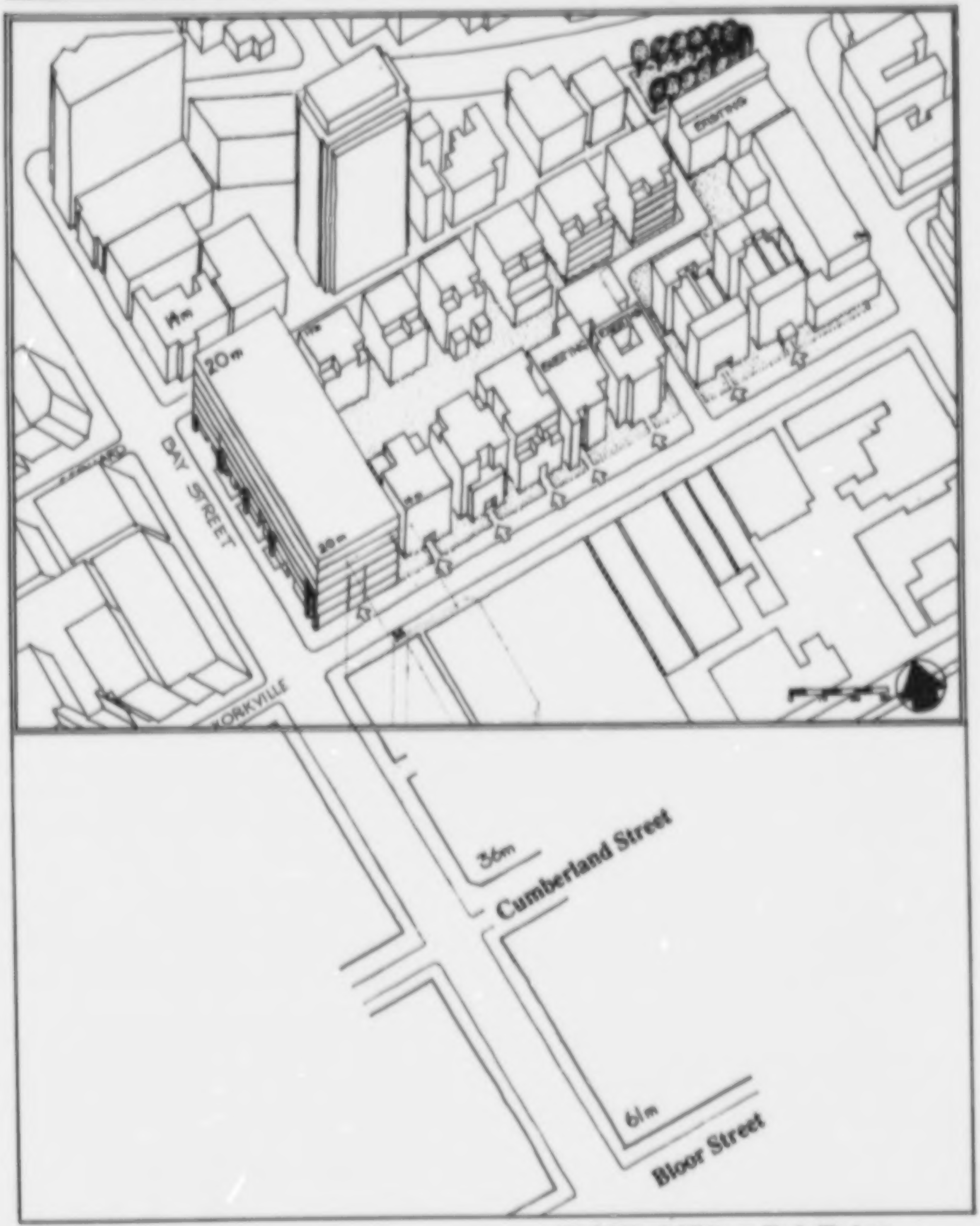

14m
20m
20m
EXISTING
EXISTING
DAY STREET
YORKVILLE
36m
Cumberland Street
61m
Bloor Street

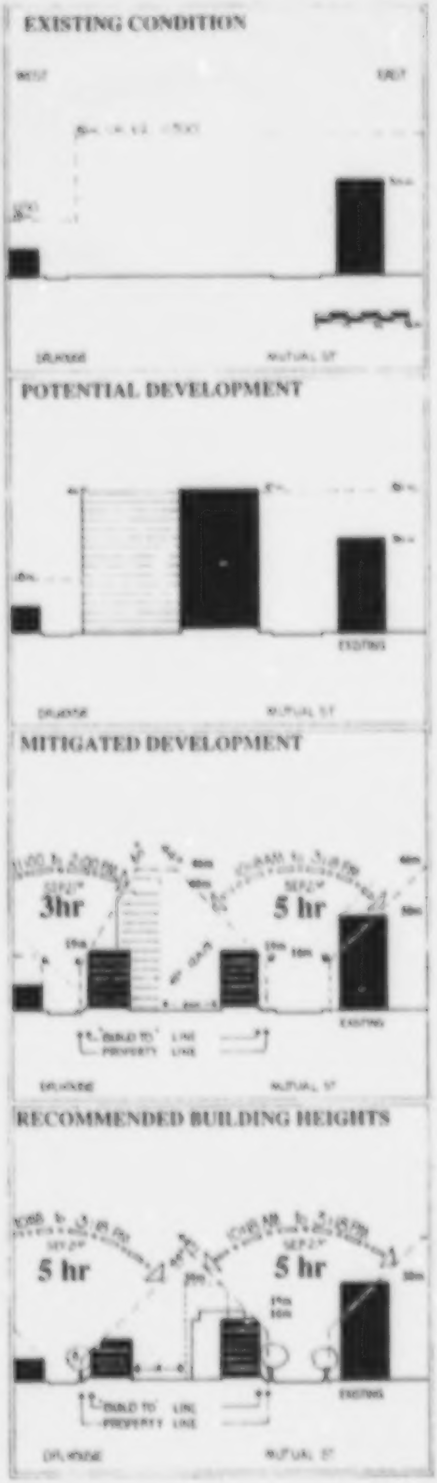
Fig 7.2 North Midtown-Yorkville Area Comfort Controls. Recommended Height Limits

East Downtown

The city block between Shuter, Mutual, Queen, and Dalhousie Streets in East Downtown is shown in Figs. 7.3 and 7.4. A reduction of zoning heights from 46m currently to 30m -- brought about by the proposed sun access standard of five hours for Mutual and Dalhousie Streets (7.3)-- would result in a density reduction from seven times coverage to four times coverage. The sun access controls would permit building height up to 30m close to the center of the block.

Additional block studies, similar to those shown here should be prepared for Dundas and Queen Streets and for Bond and Jarvis Streets. If these studies demonstrate that a 30m building height does not create adverse shadow impacts for courtyards or shading of rear windows, then the 30m building height would be appropriate for medium density areas in East Downtown.

In the Mutual-Dalhousie, Queen and Shuter block shown here, due to its relatively narrow width, a 30m height would shade the rear windows of the townhouses along Dalhousie in the morning. A building height limit of 20m would produce an optimum condition.



EXISTING CONDITION

POTENTIAL DEVELOPMENT

MITIGATED DEVELOPMENT

RECOMMENDED BUILDING HEIGHTS

Fig 7.3 East Downtown-Future Development Comfort Controls. Recommended Building Heights

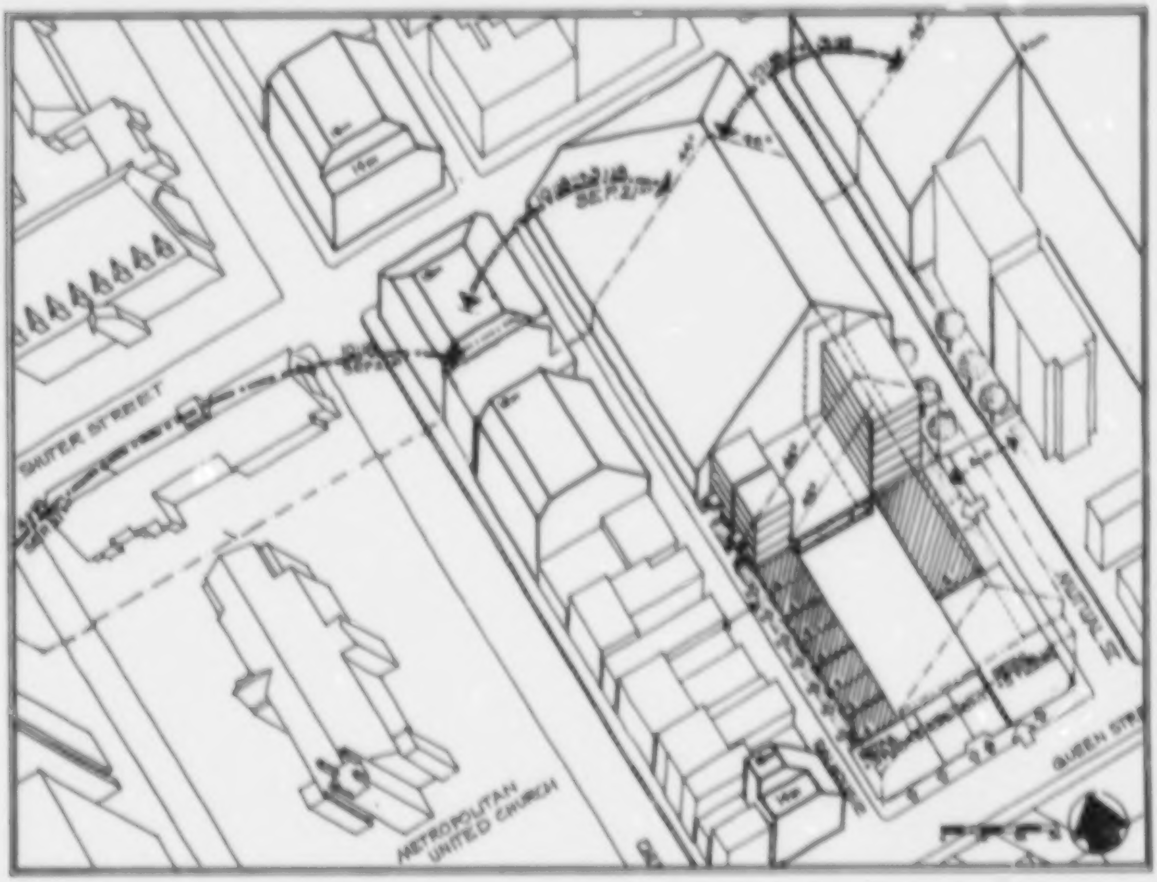

SHUTER STREET
14m
METROPOLITAN UNITED CHURCH
QUEEN STR

Fig 7.4 East Downtown-Future Development Comfort Controls. Recommended Building Heights

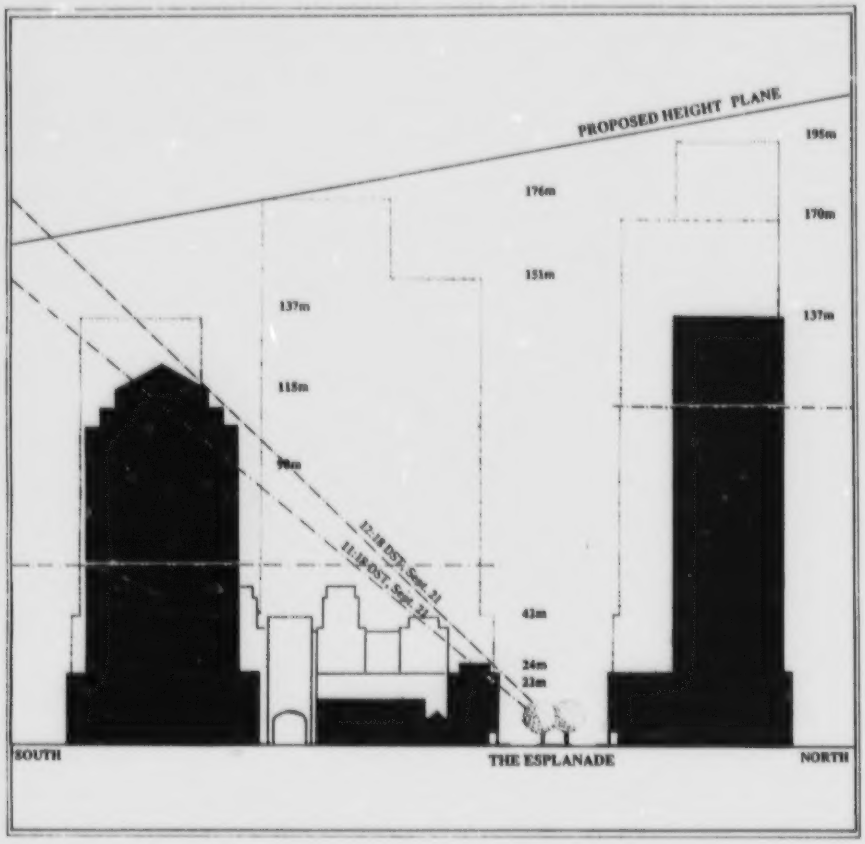

PROPOSED HEIGHT PLANE
195m
176m
170m
151m
137m
137m
115m
90m
12:18 DST, Sept. 21
11:18 DST, Sept. 21
43m
24m
22m
SOUTH
THE ESPLANADE
NORTH

Fig 7.5 Lakefront Area-
Future Development Comfort Controls

Lakefront Area

Block studies along York and Simcoe Streets between the new Esplanade and the Gardiner Esplanade showed lower densities than those currently considered for this area. A five-hour sun access standard for York and Simcoe Streets would limit building heights to 22m along these streets, and an overall height limit of 90m. Sun access standard for Roundhouse Park, preserving sunlight for the entire year, from one-and-a-half hours after sunrise, to one-and-a-half hours before sunset, would further restrict the overall height limit to 60m in this city block. The density would be lowered significantly. The building silhouettes shown in black on Figs. 7.5 and 7.6 total a density of 8 times coverage.

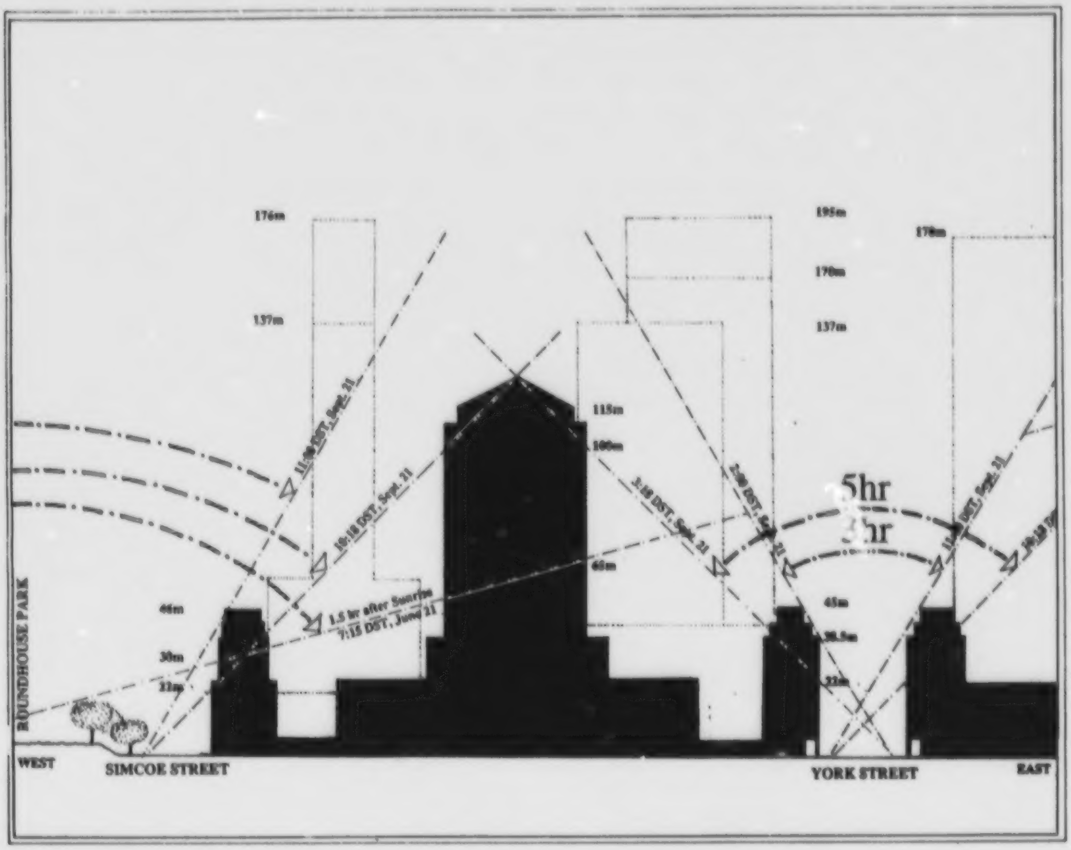

176m
137m
195m
170m
137m
176m
11:00 DST, Sept. 21
10:18 DST, Sept. 21
1.5 hr after Sunrise
7:15 DST, June 21
115m
100m
60m
3:18 DST, Sept. 21
2:00 DST, Sept. 21
5hr
3hr
DST, Sept. 21
46m
30m
22m
45m
38.5m
22m
ROUNDHOUSE PARK
WEST
SIMCOE STREET
YORK STREET
EAST

Fig 7.6 Lake Front Area--
Future Development Comfort Controls

The recommended five-hour standard for York and the Esplanade would lower this density to 7 times coverage. A lowering of the height limit due to sun access for Roundhouse Park would further lower the density to 6 times coverage in the western section of the block near Simcoe Street.

However the character of such a development would be highly urban and can be compared to the rows of buildings that line Central Park in New York City.

The dotted lines shown on Figs. 7.5 and 7.6 indicate building volumes currently considered for this city block. It is self-evident from this comparison that sunlight would not reach Roundhouse Park for the entire period when the sun

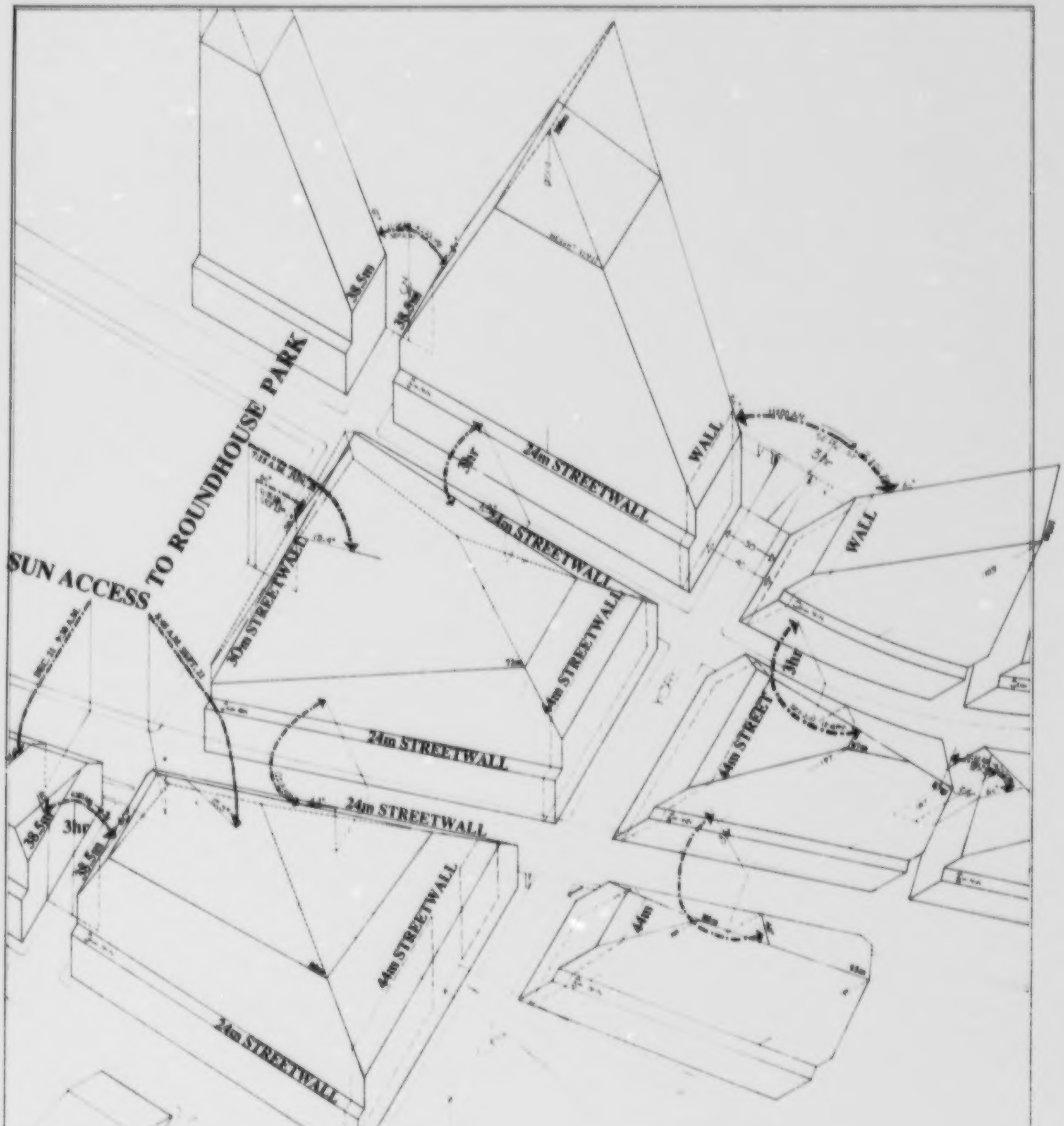

SUN ACCESS TO ROUNDHOUSE PARK
38.5m
38.5m
3hr
WALL
5hr
WALL
24m STREETWALL
24m STREETWALL
30m STREETWALL
44m STREETWALL
3hr
24m STREETWALL
24m STREETWALL
44m STREET
3hr
3hr
38.5m
38.5m
44m STREETWALL
44m
24m STREETWALL

Fig 7.7 Lakefront-Railway Lands, Comfort Controls--Allowable Height Envelopes, 3 Hour

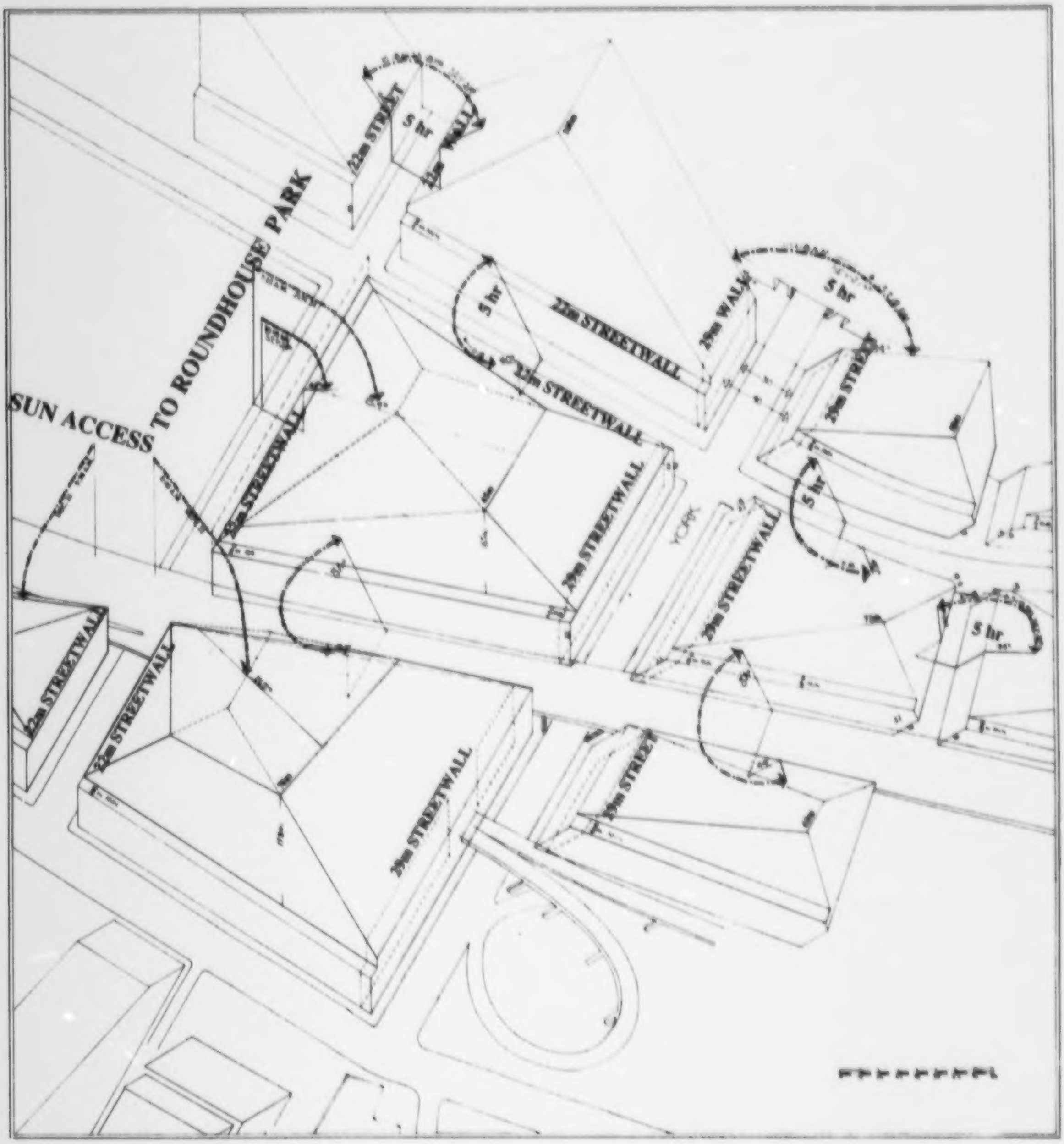

SUN ACCESS TO ROUNDHOUSE PARK
22m STREET
22m WALL
5 hr
22m STREETWALL
22m STREETWALL
29m WALL
5 hr
29m STREET
5 hr
22m STREETWALL
29m STREETWALL
YORK
29m STREETWALL
5 hr
22m STREETWALL
22m STREETWALL
29m STREETWALL
29m STREET

Fig 7.8 Lakefront Railway Lands Comfort Controls--Allowable Height Envelopes, 5 Hour

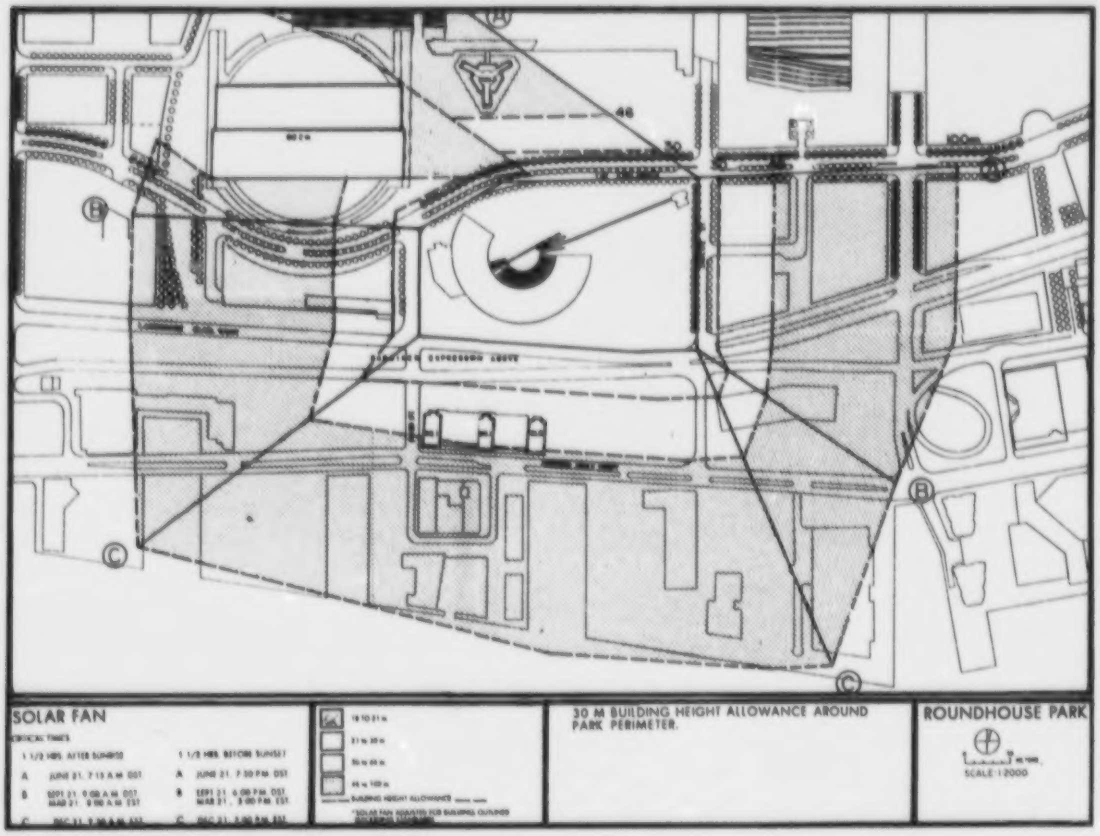

A
B
C
46
30
100m
SOLAR FAN
1 1/2 HRS. AFTER SUNRISE
1 1/2 HRS. BEFORE SUNSET
BUILDING HEIGHT ALLOWANCE
30 M BUILDING HEIGHT ALLOWANCE AROUND PARK PERIMETER.
ROUNDHOUSE PARK
SCALE 1:2000

Fig. 7.9 Solar Fan for Roundhouse Park

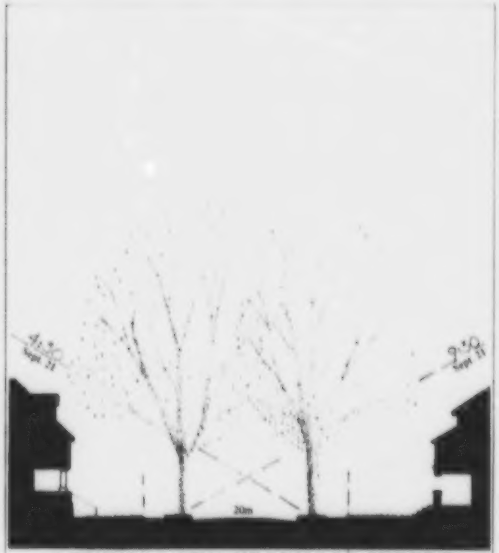
traverses the eastern sky each and every day of the year. Only when the sun has reached a position to the south, above Simcoe Street, would sunlight start to fall on the new park. For example, the row of 137m-high towers closest to Simcoe Street would create shadows well beyond John Street on the western side of the park at 8 a.m. in June. At 10:30 a.m. in June, the same shadows will have traversed the Park and will fall clear across the park north of the Esplanade and south of the CN tower.

The various sun access standards are again compared in Figs. 7.7 and 7.8. The building height limits and height envelopes possible under the recommendation of this report are summarized in Fig. 7.8.

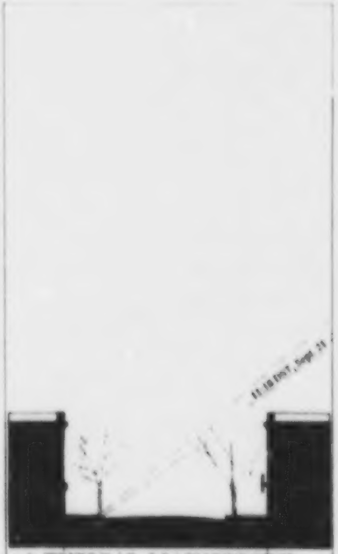
The mitigation of wind velocities in the Railway Lands and along the Lakefront are an important concern. The potential build-out under any future plan should be modeled. The cumulative wind effects of such buildings should be analyzed in the wind tunnel.

Streets For All Seasons

Finally, attention should again focus on streets as public areas of the City. This study was motivated by a concern for the quality of the street environment. It is official policy of the City to encourage public streets which have a well-defined character, scale, and enclosure to ensure that they are comfortable and convenient, and offer varied activities and experiences to pedestrians.The design of streets is primarily the concern of city government. Streets make up almost one-third of the entire surface area of the City. If this area is designed well, an important part of a City's character is defined. Within the public right of way, no other single design element defines streets better than trees planted in rows to create canopies, or double rows to create trellised walks.



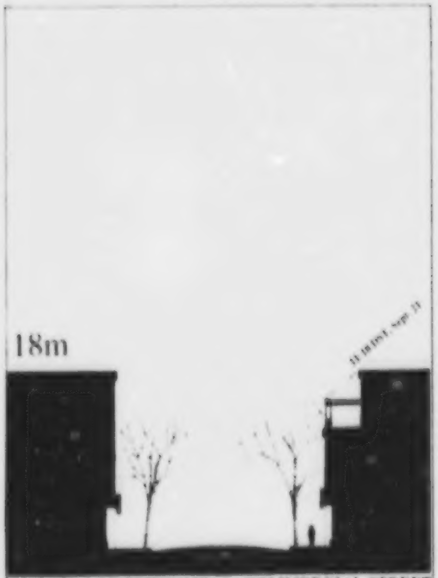
A TYPICAL NEIGHBORHOOD STREET



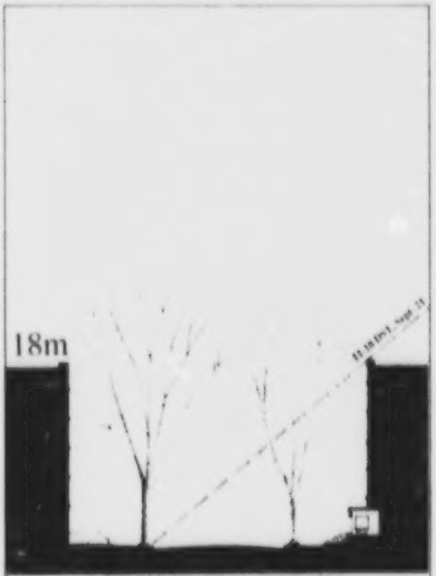
A TYPICAL MAINSTREET

Significant use has been made of street trees in Toronto's neighborhoods. Having reached maturity, these trees easily reach across streets, creating a "roof" that provides enclosure and improves the microclimate.

Streets in Toronto's Central Area should be designed for use during all seasons. Sun access and wind controls will provide comfort and shelter during the shoulder seasons, when direct sunlight is essential for pedestrian comfort. At all times of the year, a choice should exist on every street in Toronto to walk in the sun or shade, depending on climatic conditions and a person's need for comfort. Streets lined with deciduous trees would let sunlight reach sidewalks during the shoulder seasons when trees are without leaves. During the summer months, leaves create shade. The spacing of trees and the selection of tree species should take into consideration the creation of a uniform canopy.



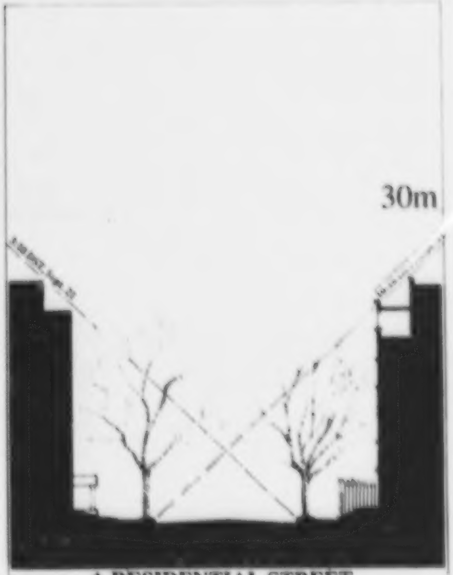
A MIXED USE RESIDENTIAL / COMMERCIAL STREET
18m HEIGHT ZONE



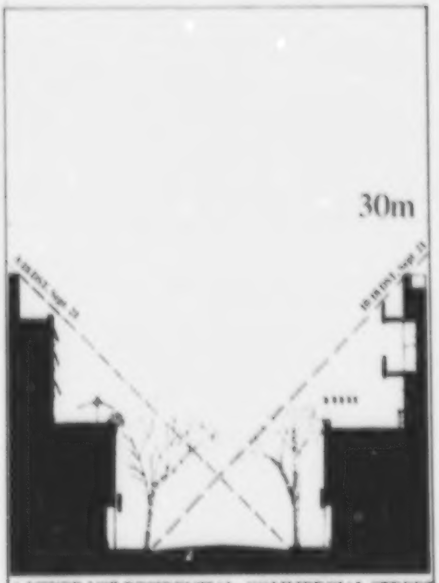
A RESIDENTIAL STREET
18m HEIGHT ZONE

On wide sidewalks the trees could be planted in double rows. On one side of the street, a double row could create a shaded promenade for hot and humid days, and on the other sidewalk a single row of trees could create a comfortable walk for those summer days with moderate temperatures when some sunlight is desired for comfort.

Street trees that allow sunlight to filter down to pedestrians include a number of Ash species. They will grow 15m tall and branch to a diameter of 7m. If planted at a distance of 7 to 8m, the trees create a canopy. A sidewalk planted in such a manner would provide pleasant comfort conditions on those days when temperatures are moderate and some sunlight is required for leisurely strolling. Similarly, Linden trees make excellent street trees. They produce a unique light quality due to their pale green leaf coloring.



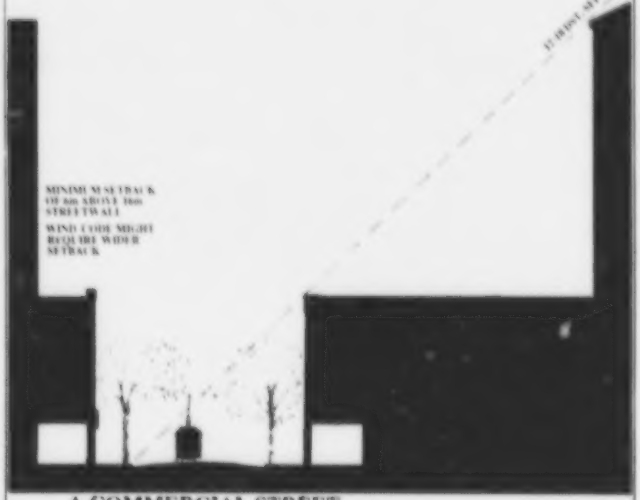
A RESIDENTIAL STREET
IN A 30m HEIGHT ZONE



A MIXED USE RESIDENTIAL , COMMERCIAL STREET
IN A 30m HEIGHT ZONE

For sidewalks where solid shadows are desired, the traditional street trees in Toronto are the Norway Maple SP. Norway Maples and Oaks grow tall and dense. On some of the wider streets in Toronto's Central Area, maples could have a stunning visual effect. They could -- for example -- turn the character of University Avenue into that of a truly major city boulevard. Walking and sitting under rows of maple trees would be very comfortable on hot and humid summer days.

In the winter, trees will allow sunlight to reach sidewalks, but on very cold and windy days they will have no effect on the comfort of pedestrians. During the cold season, buildings have to provide shelter. Arcades open to the sidewalk along busy commercial streets could run parallel to sidewalks. These arcades would provide shelter from snow, rain, and wind. An urban design plan should be prepared that demonstrates where the opportunity exists to introduce arcades along streets in Toronto's Central Area.

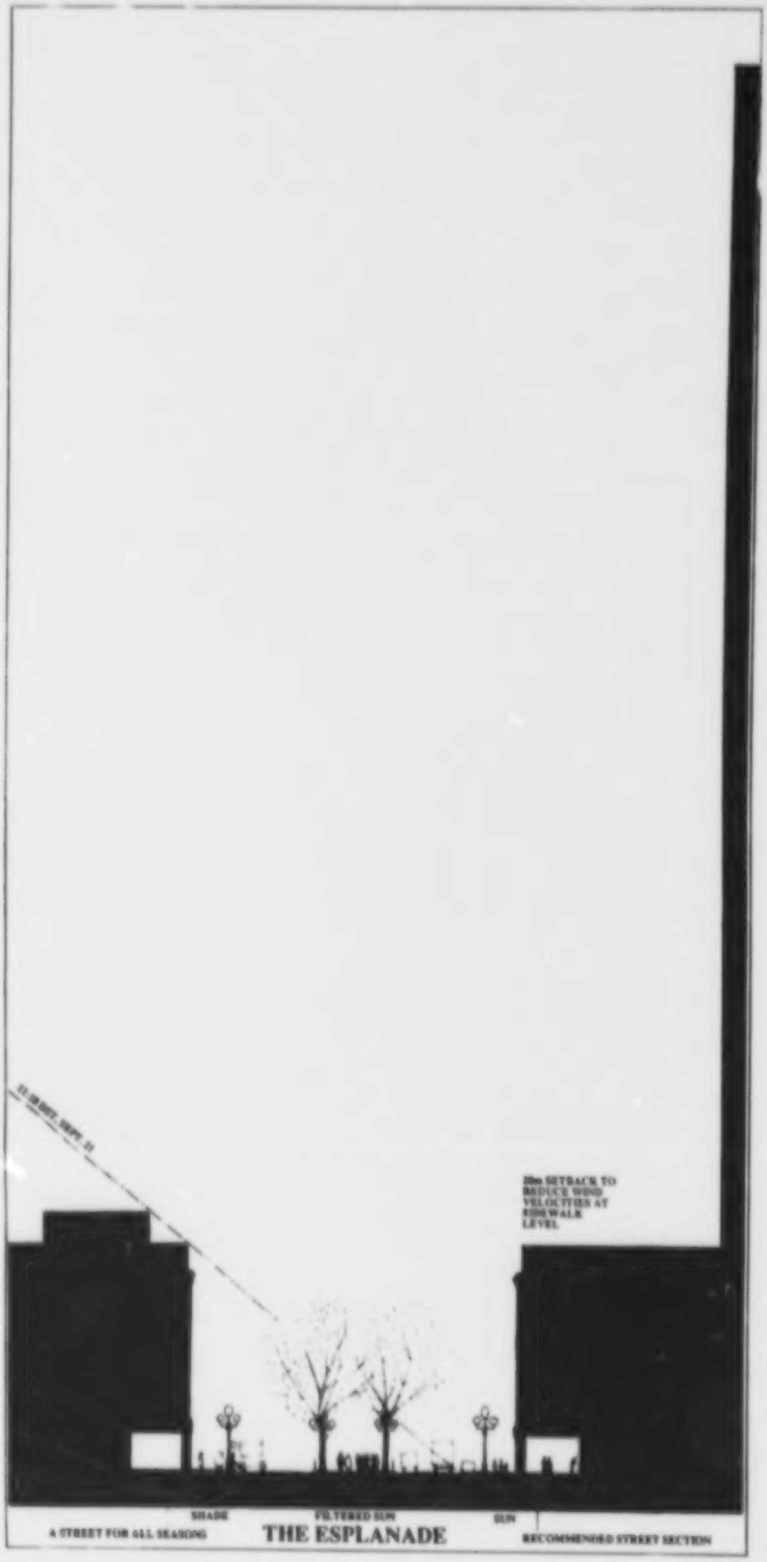

MINIMUM SETBACK OF 6m ABOVE 16m STREETWALL
WIND CODE MIGHT REQUIRE WIDER SETBACK
12:18 DST SEPT 21

A COMMERCIAL STREET
IN A 46m HEIGHT ZONE

An obvious opportunity for arcades exists in Toronto's Lakefront area, and in the development of the Railway Lands. It is the intent of city policy to reconnect the City to the lake through an extension of the existing street pattern southward to the former harbour front. Along streets such as Young, Bay, York, Simcoe, John, Peter, and Spadina unique opportunities exist to create streets that are walkable links to the newly reclaimed lakefront. Instead of new extensive underground walkways, arcades open to sidewalks should be considered in these public rights-of-way. On York Street, for example, the distance between buildings will measure 40m. Here the space is available to allow arcade structures built along the property line.

The arcades could accommodate pedestrians walking along retail stores.

The section drawings on pages 25, 45, 46, 47, 55, and 151-156 have been drawn at the same scale and reduced to approximately 1cm = 7m (1: 700).


12:00 EST, SEPT. 21
20m SETBACK TO REDUCE WIND VELOCITIES AT SIDEWALK LEVEL
SHADE
FILTERED SUN
SUN
A STREET FOR ALL SEASONS
THE ESPLANADE
RECOMMENDED STREET SECTION

The sidewalks outside the arcades would be wide enough to provide sunny walks during those times when people prefer sunlight. During warm periods, the arcade spaces would be attractive places for outdoor restaurants. The high residential density proposed for this area combined with significant commercial development, plus the City's largest sports facility, a busy commuter rail terminal, and an active lakefront, makes this reintegrated part of the City a unique opportunity for a city design where streets are enjoyable during all seasons.

APPENDIX I

Appendix 1.1 Calculating Solar Angles

The calculation of solar angles is a complex geometric task. In order to determine the correct altitude (vertical angle) and azimuth (horizontal or bearing angle) for a specific latitude at a given point requires the use of two formulas given below:

sin altitude = (sin of the latitude) X (sin of the declination of the earth for a given date) + (cos of the latitude) X (cos of the declination of the earth for the same date) X cos of the minutes from solar noon)

sin azimuth = (cos of the declination for a given date) X (sin of the minutes from solar noon) / (cos of the altitude).
Note: when azimuth angles are greater than 90 degrees from south they must be subtracted from 180 degrees

In order to determine the number of minutes from solar noon the Longitude of an given location must be compared to the meridian of the time zone in which a city is located . In addition, an Equation of Time factor for a given day must be added. (The Equation of Time is the time adjustment required due to the influence of the different velocity at which the earth travels on its elliptical orbit around the sun.) The formula for solar time is;

solar time = standard time + 4 X (longitude of Eastern Standard Time - longitude of a given location) + the Equation of Time

For example; Toronto City Hall is located at longitude 79 degrees 23 minutes (79.38), the time zone is the Eastern Standard Time zone of longitude 75 degrees. For September 21 at Toronto's longitude the equation of time given by the Astronomical Almanac proposed by the United States Naval Observatory is 6.767 minutes by the formula:

solar time = standard time - 4 X (75-79.38) + 6.767 = -10.753

This means that solar noon, in September, or when the sun is at its highest, occurs at approximately 12:10 p.m. Eastern Standard Time. If you consider that Toronto is on Daylight Saving Time in September, solar noon will occur at approximately 1:10 p.m. local time (12:00 noon local time, then, is 70 minutes from solar noon).

This Appendix includes a set of solar altitude and azimuth charts calculated for the latitude and longitude of Toronto City Hall at the 21st of each month in 15-minute increments from sunrise to sunset. The charts are accurate to approximately one minute in time and 1 degree in altitude and azimuth readings. The given angles do not include any defraction factors due to sun angles with respect to the atmosphere or other atmospheric conditions.

DETERMINING SOLAR STANDARDS FOR SOLAR ACCESS TO OPEN SPACES

As planners and designers, we wish to set rational standards for the protection of solar access to our open spaces and streets. We would also like these standards to be equitable and easy to apply. These standards need to be related to local times so that we can set appropriate standards based on the times when open spaces are used. As we have seen, the calculations for solar altitudes and azimuths are complex. There are variations from month to month due to the declination of the Earth, the Equation of Time, and the time shifts caused by the differences between Eastern Standard Times and Daylight Saving Times.

As part of the study, we determined that there were three critical local time variations which should be used to set solar access to open spaces found under typical urban conditions. These were:

1) solar access to the total perimeter of a park from 1-1/2 hours after sunrise and 1-1/2 hours before sunset, local time

2) solar access from 10:00 a.m. to 4:00 p.m., local time (6 hours of access) from the spring to the fall equinox

3) solar access from 11:00 a.m. to 2:00 p.m., local time (3 hours of access) from the spring to the fall equinox

When related to specific open spaces, these time windows determine the altitude and azimuths required to ensure solar access to a given point on the ground.

ASSUMPTIONS IN DETERMINING CRITICAL ALTITUDE AND AZIMUTHS FOR SOLAR ACCESS

In a month-by-month study of the altitude and azimuth angles based on the 21st of each month (times which correspond to the highest and lowest sun angles), we have identified the critical altitude and azimuth angles which meet the intent of the standards related to local time and variations in solar time. In setting these standards, we have made assumptions on the time variation from solar noon, and the local time of sunrise and sunset.

Over all the months, the local variation of solar noon to local noon ranges from 31 minutes past noon (February) to 2 minutes past noon (October). If one averages the variation over all months, a time of 18 minutes reflects a practical time variation that can be set for all months.

The first standard mentioned above also requires that we identify the altitude and azimuths for 1.5 hours after sunrise and 1.5 hours before sunset. In reality, this calculation is very complex due to the defraction of light entering the Earth's atmosphere. This defraction is related to the angle of the sun relative to the Earth's declination and local atmospheric variations(such as pollution). For practical purposes, we have calculated the sunrise and sunset angles using a formula that does not include defraction. This is done by calculating day length and subtracting half the time from solar noon to get the time of sunrise and adding half the time to solar noon to get the time of sunset. This formula for day length is:

day length = 2 /15 Arc cos (-tan latitude X tan declination)

For example: for September at latitude 43.65 and declination of 0.99, the length of day is calculated at 12.13 hours. Assuming solar noon at 12.3 p.m., sunrise would occur at 12.3 - (12.13/2) or 6.24 a.m. EST, and sunset at 6.36 p.m. EST. Since September is on Daylight Savings Time, sunrise (converted to hours, minutes, and seconds) would be 7:14 a.m. and sunset would be 7:21 p.m. To each of these times, 1.5 hours is added to the sunrise time and 1.5 hours is subtracted from the sunset time to get the times required for our standard. In our example, the standard would set the attitudes and azimuths at 8:44 a.m. and 5:51 p.m. as the desirable window for solar access.

The times, altitudes, and azimuths used for each of the standards are summarized below.

GENERAL TECHNICAL IMPLICATIONS OF THE ALTITUDES AND AZIMUTHS GIVEN IN THE OPEN SPACE STANDARDS

The solar fans generated in this report are based on the azimuths and altitudes given in this appendix. In Standard 1 they were derived from the study of four critical months. These were March 21st, June 21st, September 21st, and December 21st. For Standards 2 and 3 they were derived from the study of three critical months that fall between the spring and fall equinox. These were March 21st, June 21st, and September 21st.

In order to understand the implication of the standards relative to average cut-off angles and azimuths that generally would result, the following summary is provided.

For standard 1 above, the altitude angles range from 12.07 degrees on December 21st to 16.26 on September 21st. This represents a variation over all months of approximately 4 degrees. On average, then, a cutoff angle of 14 degrees and an azimuth of 108 degrees east and west of due south (a total of 216 degrees) would protect the majority of solar access throughout the year to the perimeter of a park.

In standard 2, the variation in altitude angles is more varied, ranging from 21.57 degrees on March 21st to 48.83 degrees on April 21st, a difference of 27.26 degrees. An average altitude of 45 degrees with an azimuth of 76 degrees east and 76 degrees west of due south (a total of 152 degrees) and a cutoff angle of 30 degrees and an azimuth of 56 degrees east and 70 degrees west of due south (a total of 126 degrees) would allow solar access to the majority of open spaces, based on this standard.

In standard 3, the variation in altitude angles is also more varied, ranging from 38.76 degrees on March 21st to 66.32 degrees on June 21st, a difference of 27.56 degrees. An average altitude of 60 degrees with an azimuth of 60 degrees east and 30 degrees west of due south (a total of 90 degrees) and a cutoff angle of 40 degrees, with an azimuth of 40 degrees east and 40 degrees west of due south (a total of 80 degrees), would allow solar access to the majority of open spaces based on this standard.

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude 43 Deg. 39 Min. North			43.65
4	longitude 79 Deg. 23MIN			79.38
5	Declination JANUARY 21st			-20.06
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		21.00	
14				
15	solar time= S. time +4(lo std-lo loc)+equation of time			
16				
17	**JANUARY 21ST**			
18	SUNRISE 7:45 AM, SUNSET 5:12 PM EST			
19				
20	TIME EST	ALTITUDE	AZIMUTH	MIN-NOON
21	4:00:00 AM	-40.23	100.72	508.00
22	4:15:00 AM	-37.55	97.78	493.00
23	4:28:00 AM	-35.21	95.34	480.00
24	4:30:00 AM	-34.85	94.97	478.00
25	4:45:00 AM	-32.14	92.27	463.00
26	5:00:00 AM	-29.43	89.65	448.00
27	5:15:00 AM	-26.72	87.10	433.00
28	5:28:00 AM	-24.37	84.94	420.00
29	5:30:00 AM	-24.01	84.61	418.00
30	5:45:00 AM	-21.32	82.15	403.00
31	6:00:00 AM	-18.64	79.72	388.00
32	6:15:00 AM	-15.98	77.30	373.00
33	6:28:00 AM	-13.70	75.20	360.00
34	6:30:00 AM	-13.35	74.88	358.00
35	6:45:00 AM	-10.74	72.45	343.00
36	7:00:00 AM	-8.17	70.01	328.00
37	7:15:00 AM	-5.64	67.54	313.00
38	7:28:00 AM	-3.49	65.37	300.00
39	7:30:00 AM	-3.16	65.03	298.00
40	7:45:00 AM	-0.73	62.48	283.00
41	8:00:00 AM	1.65	59.89	268.00
42	8:15:00 AM	3.97	57.23	253.00
43	8:28:00 AM	5.92	54.87	240.00
44	8:30:00 AM	6.21	54.50	238.00
45	8:45:00 AM	8.38	51.70	223.00
46	9:00:00 AM	10.47	48.83	208.00
47	9:15:00 AM	12.46	45.87	193.00
48	9:28:00 AM	14.11	43.23	180.00
49	9:30:00 AM	14.36	42.81	178.00
50	9:45:00 AM	16.15	39.67	163.00
51	10:00:00 AM	17.82	36.43	148.00
52	10:15:00 AM	19.37	33.09	133.00
53	10:28:00 AM	20.60	30.12	120.00
54	10:30:00 AM	20.78	29.65	118.00
55	10:45:00 AM	22.05	26.12	103.00
56	11:00:00 AM	23.17	22.50	88.00
57	11:15:00 AM	24.12	18.80	73.00
58	11:28:00 AM	24.82	15.54	60.00
59	11:30:00 AM	24.91	15.03	58.00
60	11:45:00 AM	25.53	11.20	43.00
61	12:00:00 PM	25.97	7.32	28.00
62	12:15:00 PM	26.22	3.40	13.00
63	12:30:00 PM	26.29	-0.52	-2.00
64	12:28:00 PM	26.29	0.00	0.00
65	12:45:00 PM	26.17	4.45	17.00
66	1:00:00 PM	25.87	8.35	32.00
67	1:15:00 PM	25.38	12.22	47.00
68	1:28:00 PM	24.82	15.54	60.00
69	1:30:00 PM	24.72	16.04	62.00
70	1:45:00 PM	23.89	19.80	77.00
71	2:00:00 PM	22.89	23.48	92.00
72	2:15:00 PM	21.73	27.07	107.00
73	2:28:00 PM	20.60	30.12	120.00
74	2:30:00 PM	20.42	30.58	122.00
75	2:45:00 PM	18.97	33.99	137.00
76	3:00:00 PM	17.39	37.30	152.00
77	3:15:00 PM	15.68	40.52	167.00
78	3:28:00 PM	14.11	43.23	180.00
79	3:30:00 PM	13.86	43.64	182.00
80	3:45:00 PM	11.94	46.66	197.00
81	4:00:00 PM	9.92	49.60	212.00
82	4:15:00 PM	7.81	52.46	227.00
83	4:28:00 PM	5.92	54.87	240.00
84	4:30:00 PM	5.62	55.24	242.00
85	4:45:00 PM	3.35	57.94	257.00
86	5:00:00 PM	1.02	60.58	272.00
87	5:15:00 PM	-1.37	63.17	287.00
88	5:28:00 PM	-3.49	65.37	300.00
89	5:30:00 PM	-3.82	65.70	302.00
90	5:45:00 PM	-6.31	68.20	317.00
91	6:00:00 PM	-8.85	70.86	332.00
92	6:15:00 PM	-11.43	73.10	347.00
93	6:28:00 PM	-13.70	75.20	360.00
94	6:30:00 PM	-14.05	75.52	362.00
95	6:45:00 PM	-16.69	77.94	377.00
96	7:00:00 PM	-19.35	80.36	392.00
97	7:15:00 PM	-22.03	82.80	407.00
98	7:28:00 PM	-24.37	84.94	420.00
99	7:30:00 PM	-24.73	85.27	422.00
100	7:45:00 PM	-27.44	87.78	437.00
101	8:00:00 PM	-30.15	89.86	452.00

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude 43 Deg. 39 Min. North			43.65
4	longitude 79 Deg. 23MIN			79.38
5	Declination FEBRUARY 21st			-10.82
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		52.00	
14				
15	solar time= S. time +4(lo std-lo loc)+equation of time			
16				
17	**FEBRUARY 21ST**			
18	SUNRISE 7:09 AM, SUNSET 5:54 PM EST			
19				
20	TIME EST	ALTITUDE	AZIMUTH	MIN-NOON
21	4:00:00 AM	-34.38	109.78	511.00
22	4:15:00 AM	-31.80	106.63	496.00
23	4:30:00 AM	-29.18	103.63	481.00
24	4:31:00 AM	-29.01	103.43	480.00
25	4:45:00 AM	-26.58	100.74	466.00
26	5:00:00 AM	-23.85	97.94	451.00
27	5:15:00 AM	-21.16	95.22	436.00
28	5:30:00 AM	-18.45	92.57	421.00
29	5:31:00 AM	-18.27	92.39	420.00
30	5:45:00 AM	-15.74	89.96	406.00
31	6:00:00 AM	-13.03	87.39	391.00
32	6:15:00 AM	-10.32	84.84	376.00
33	6:30:00 AM	-7.62	82.30	361.00
34	6:31:00 AM	-7.45	82.13	360.00
35	6:45:00 AM	-4.94	79.75	346.00
36	7:00:00 AM	-2.29	77.20	331.00
37	7:15:00 AM	0.35	74.62	316.00
38	7:30:00 AM	2.94	72.01	301.00
39	7:31:00 AM	3.12	71.83	300.00
40	7:45:00 AM	5.51	69.35	286.00
41	7:00:00 AM	-2.29	77.20	331.00
42	8:15:00 AM	10.48	63.87	256.00
43	8:30:00 AM	12.89	61.02	241.00
44	8:31:00 AM	13.05	60.83	240.00
45	8:45:00 AM	15.23	58.09	226.00
46	9:00:00 AM	17.49	55.06	211.00
47	9:15:00 AM	19.68	51.93	196.00
48	9:30:00 AM	21.76	48.69	181.00
49	9:31:00 AM	21.90	48.46	180.00
50	9:45:00 AM	23.75	45.32	166.00

	A	B	C	D
51	10:00:00 AM	25.62	41.83	151.00
52	10:15:00 AM	27.36	38.20	136.00
53	10:30:00 AM	28.97	34.44	121.00
54	10:31:00 AM	29.07	34.19	120.00
55	10:45:00 AM	30.43	30.55	106.00
56	11:00:00 AM	31.72	26.52	91.00
57	11:15:00 AM	32.85	22.37	76.00
58	11:30:00 AM	33.79	18.11	61.00
59	11:31:00 AM	33.84	17.82	60.00
60	11:45:00 AM	34.53	13.75	46.00
61	12:00:00 PM	35.07	9.31	31.00
62	12:15:00 PM	35.41	4.82	16.00
63	12:30:00 PM	35.53	0.30	1.00
64	12:31:00 PM	35.53	0.00	0.00
65	12:45:00 PM	35.44	4.22	14.00
66	1:00:00 PM	35.13	8.72	29.00
67	1:15:00 PM	34.62	13.16	44.00
68	1:30:00 PM	33.90	17.53	59.00
69	1:31:00 PM	33.84	17.82	60.00
70	1:45:00 PM	32.98	21.81	74.00
71	2:00:00 PM	31.88	25.98	89.00
72	2:15:00 PM	30.61	30.02	104.00
73	2:30:00 PM	29.17	33.93	119.00
74	2:31:00 PM	29.07	34.19	120.00
75	2:45:00 PM	27.59	37.71	134.00
76	3:00:00 PM	25.86	41.35	149.00
77	3:15:00 PM	24.00	44.86	164.00
78	3:30:00 PM	22.03	48.24	179.00
79	3:31:00 PM	21.90	48.46	180.00
80	3:45:00 PM	19.96	51.50	194.00
81	4:00:00 PM	17.79	54.65	209.00
82	4:15:00 PM	15.54	57.69	224.00
83	4:30:00 PM	13.21	60.64	239.00
84	4:31:00 PM	13.05	60.83	240.00
85	4:45:00 PM	10.81	63.50	254.00
86	5:00:00 PM	8.35	66.28	269.00
87	5:15:00 PM	5.84	69.00	284.00
88	5:30:00 PM	3.29	71.66	299.00
89	5:31:00 PM	3.12	71.83	300.00
90	5:45:00 PM	0.69	74.28	314.00
91	6:00:00 PM	-1.93	76.86	329.00
92	6:15:00 PM	-4.59	79.41	344.00
93	6:30:00 PM	-7.27	81.96	359.00
94	6:31:00 PM	-7.45	82.13	360.00
95	6:45:00 PM	-9.96	84.50	374.00
96	7:00:00 PM	-12.67	87.05	389.00
97	7:15:00 PM	-15.38	89.62	404.00
98	7:30:00 PM	-18.09	92.22	419.00
99	7:31:00 PM	-18.27	92.39	420.00
100	7:45:00 PM	-20.80	94.87	434.00
101	8:00:00 PM	-23.50	97.57	449.00

	A		C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude: 43 Deg. 39 Min. North			43.65
4	longitude 79 Deg. 23MIN			79.38
5	Declination MARCH 21st			-0.05
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		80.00	
14				
15	solar time= S. time +4(lo std-lo loc)+equation of time			
16				
17	**MARCH 21ST**			
18	SUNRISE 6:22 AM, SUNSET 6:29 PM			
19				
20	TIME EST	ALTITUDE	AZIMUTH	MIN-NOON
21	4:00:00 AM	-25.37	116.81	505
22	4:15:00 AM	-22.92	113.70	490
23	4:25:00 AM	-21.25	111.69	480
24	4:30:00 AM	-20.40	110.70	475
25	4:45:00 AM	-17.84	107.81	460
26	5:00:00 AM	-15.24	104.99	445
27	5:15:00 AM	-12.60	102.24	430
28	5:25:00 AM	-10.83	100.44	420
29	5:30:00 AM	-9.94	99.55	415
30	5:45:00 AM	-7.25	96.90	400
31	6:00:00 AM	-4.55	94.29	385
32	6:15:00 AM	-1.84	91.69	370
33	6:25:00 AM	-0.03	89.96	360
34	6:30:00 AM	0.87	89.10	355
35	6:45:00 AM	3.58	86.51	340
36	7:00:00 AM	6.28	83.90	325
37	7:15:00 AM	8.98	81.26	310
38	7:25:00 AM	10.76	79.49	300
39	7:30:00 AM	11.65	78.59	295
40	7:45:00 AM	14.29	75.86	280
41	7:00:00 AM	6.28	83.90	325
42	8:15:00 AM	19.48	70.20	250
43	8:25:00 AM	21.17	68.24	240
44	8:30:00 AM	22.01	67.24	235
45	8:45:00 AM	24.48	64.17	220
46	9:00:00 AM	26.89	60.98	205
47	9:15:00 AM	29.22	57.65	190
48	9:25:00 AM	30.73	55.35	180
49	9:30:00 AM	31.47	54.17	175
50	9:45:00 AM	33.62	50.53	160
51	10:00:00 AM	35.66	46.70	145
52	10:15:00 AM	37.56	42.67	130
53	10:25:00 AM	38.76	39.88	120
54	10:30:00 AM	39.33	38.45	115
55	10:45:00 AM	40.93	34.01	100
56	11:00:00 AM	42.36	29.37	85
57	11:15:00 AM	43.59	24.53	70
58	11:25:00 AM	44.29	21.20	60
59	11:30:00 AM	44.61	19.50	55
60	11:45:00 AM	45.40	14.32	40
61	12:00:00 PM	45.94	9.01	25
62	12:15:00 PM	46.24	3.62	10
63	12:25:00 PM	46.30	0.00	0
64	12:30:00 PM	46.29	1.81	5
65	12:45:00 PM	46.07	7.22	20
66	1:00:00 PM	45.61	12.56	35
67	1:15:00 PM	44.90	17.79	50
68	1:25:00 PM	44.29	21.20	60
69	1:30:00 PM	43.95	22.87	65
70	1:45:00 PM	42.79	27.78	80
71	2:00:00 PM	41.43	32.49	95
72	2:15:00 PM	39.88	36.99	110
73	2:25:00 PM	38.76	39.88	120
74	2:30:00 PM	38.17	41.29	125
75	2:45:00 PM	36.31	45.38	140
76	3:00:00 PM	34.31	49.27	155
77	3:15:00 PM	32.20	52.98	170
78	3:25:00 PM	30.73	55.35	180
79	3:30:00 PM	29.98	56.51	185
80	3:45:00 PM	27.68	59.89	200
81	4:00:00 PM	25.29	63.12	215
82	4:15:00 PM	22.84	66.23	230
83	4:25:00 PM	21.17	68.24	240
84	4:30:00 PM	20.33	69.22	245
85	4:45:00 PM	17.77	72.12	260
86	5:00:00 PM	15.17	74.94	275
87	5:15:00 PM	12.53	77.69	290
88	5:25:00 PM	10.76	79.49	300
89	5:30:00 PM	9.87	80.38	305
90	5:45:00 PM	7.18	83.02	320
91	6:00:00 PM	4.48	85.64	335
92	6:15:00 PM	1.77	88.24	350
93	6:25:00 PM	-0.03	89.96	360
94	6:30:00 PM	-0.94	90.83	365
95	6:45:00 PM	-3.65	93.42	380
96	7:00:00 PM	-6.35	96.03	395
97	7:15:00 PM	-9.05	98.66	410
98	7:25:00 PM	-10.83	100.44	420
99	7:30:00 PM	-11.72	101.34	425
100	7:45:00 PM	-14.36	104.07	440
101	8:00:00 PM	-16.96	106.86	455

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude: 43 Deg. 39 Min. North			43.65
4	longitude 79 Deg. 23MIN			79.38
5	Declination APRIL 21st			11.61
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		111.00	
14				
15	solar time= S. time +4(lo.std-lo.loc)+equation of time			
16				
17	**APRIL 21ST**			
18	SUNRISE 5:27 AM SUNSET 7:07 PM			
19				
20	TIME EST	ALTITUDE	AZIMUTH	MIN-NOON
21	4:00:00 AM	-14.92	122.82	496
22	4:15:00 AM	-12.60	119.86	481
23	4:16:00 AM	-12.44	119.69	480
24	4:30:00 AM	-10.21	117.03	466
25	4:45:00 AM	-7.77	114.26	451
26	5:00:00 AM	-5.27	111.55	436
27	5:15:00 AM	-2.72	108.89	421
28	5:16:00 AM	-2.55	108.72	420
29	5:30:00 AM	-0.14	106.29	406
30	5:45:00 AM	2.48	103.71	391
31	6:00:00 AM	5.13	101.16	376
32	6:15:00 AM	7.81	98.62	361
33	6:16:00 AM	7.98	98.46	360
34	6:30:00 AM	10.50	96.09	346
35	6:45:00 AM	13.20	93.55	331
36	7:00:00 AM	15.91	89.01	316
37	7:15:00 AM	18.62	88.40	301
38	7:16:00 AM	18.81	88.22	300
39	7:30:00 AM	21.33	85.76	286
40	7:45:00 AM	24.03	83.06	271
41	7:00:00 AM	15.91	89.01	316
42	8:15:00 AM	29.38	77.41	241
43	8:16:00 AM	29.56	77.22	240
44	8:30:00 AM	32.01	74.43	226
45	8:45:00 AM	34.61	71.32	211
46	9:00:00 AM	37.15	68.05	196
47	9:15:00 AM	39.63	64.60	181
48	9:16:00 AM	39.80	64.36	180
49	9:30:00 AM	42.05	60.93	166
50	9:45:00 AM	44.37	57.03	151
51	10:00:00 AM	46.59	52.86	136
52	10:15:00 AM	48.69	48.38	121
53	10:16:00 AM	48.83	48.07	120
54	10:30:00 AM	50.64	43.57	106
55	10:45:00 AM	52.42	38.40	91
56	11:00:00 AM	54.00	32.86	76
57	11:15:00 AM	55.36	26.95	61
58	11:16:00 AM	55.44	26.55	60
59	11:30:00 AM	56.45	20.70	46
60	11:45:00 AM	57.27	14.14	31
61	12:00:00 PM	57.77	7.36	16
62	12:15:00 PM	57.96	0.46	1
63	12:16:00 PM	57.96	0.00	0
64	12:30:00 PM	57.82	6.45	14
65	12:45:00 PM	57.35	13.25	29
66	1:00:00 PM	56.58	19.84	44
67	1:15:00 PM	55.52	26.14	59
68	1:16:00 PM	55.44	26.55	60
69	1:30:00 PM	54.20	32.10	74
70	1:45:00 PM	52.65	37.68	89
71	2:00:00 PM	50.89	42.90	104
72	2:15:00 PM	48.96	47.76	119
73	2:16:00 PM	48.83	48.07	120
74	2:30:00 PM	46.88	52.28	134
75	2:45:00 PM	44.68	56.49	149
76	3:00:00 PM	42.36	60.43	164
77	3:15:00 PM	39.96	64.12	179
78	3:16:00 PM	39.80	64.36	180
79	3:30:00 PM	37.49	67.80	194
80	3:45:00 PM	34.95	70.89	209
81	4:00:00 PM	32.36	74.03	224
82	4:15:00 PM	29.73	77.02	239
83	4:16:00 PM	29.56	77.22	240
84	4:30:00 PM	27.08	79.91	254
85	4:45:00 PM	24.39	82.69	269
86	5:00:00 PM	21.69	85.40	284
87	5:15:00 PM	18.99	88.05	299
88	5:16:00 PM	18.81	91.78	300
89	5:30:00 PM	16.27	90.65	314
90	5:45:00 PM	13.56	93.21	329
91	6:00:00 PM	10.86	95.75	344
92	6:15:00 PM	8.16	98.29	359
93	6:16:00 PM	7.98	98.46	360
94	6:30:00 PM	5.49	100.82	374
95	6:45:00 PM	2.84	103.37	389
96	7:00:00 PM	0.21	105.94	404
97	7:15:00 PM	-2.38	108.54	419
98	7:16:00 PM	-2.55	108.72	420
99	7:30:00 PM	-4.93	111.19	434
100	7:45:00 PM	-7.44	113.89	449
101	8:00:00 PM	-9.89	116.66	464

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude: 43 Deg. 39 Min. North			43.65
4	longitude 79 Deg. 23MIN			79.38
5	Declination MAY 21st			20.04
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		141.00	
14				
15	solar time= S. time +4(lo.std-lo.loc)+equation of time			
16				
17	**MAY 21ST**			
18	SUNRISE 5:48 AM SUNSET 8:41 PM DST			
19				
20	TIME DST	ALTITUDE	AZIMUTH	MIN-NOON
21	5:00:00 AM	-7.83	127.53	493
22	5:15:00 AM	-5.64	124.75	478
23	5:13:00 AM	-5.93	125.12	480
24	5:30:00 AM	-3.37	122.05	463
25	5:45:00 AM	-1.04	119.40	448
26	6:00:00 AM	1.36	116.82	433
27	6:15:00 AM	3.80	114.28	418
28	6:13:00 AM	3.47	114.62	420
29	6:30:00 AM	6.30	111.79	403
30	6:45:00 AM	8.84	109.32	388
31	7:00:00 AM	11.42	106.89	373
32	7:15:00 AM	14.03	104.46	358
33	7:13:00 AM	13.68	104.78	360
34	7:30:00 AM	16.67	102.04	343
35	7:45:00 AM	19.34	99.62	328
36	8:00:00 AM	22.02	97.18	313
37	8:15:00 AM	24.72	94.71	298
38	8:13:00 AM	24.36	95.05	300
39	8:30:00 AM	27.43	92.21	283
40	8:45:00 AM	30.14	89.64	268
41	9:00:00 AM	32.85	87.00	253
42	9:15:00 AM	35.56	84.27	238
43	9:13:00 AM	35.20	84.64	240
44	9:30:00 AM	38.25	81.43	223
45	9:45:00 AM	40.92	78.45	208
46	10:00:00 AM	43.56	75.30	193
47	10:15:00 AM	46.17	71.95	178
48	10:13:00 AM	45.82	72.41	180
49	10:30:00 AM	48.72	68.36	163
50	10:45:00 AM	51.21	64.48	148

	A	B	C	D
51	11:00:00 AM	53.81	60.25	133
52	11:15:00 AM	55.91	55.63	118
53	11:13:00 AM	55.61	56.27	120
54	11:30:00 AM	58.08	50.53	103
55	11:45:00 AM	60.09	44.89	88
56	12:00:00 PM	61.90	38.65	73
57	12:15:00 PM	63.46	31.77	58
58	12:13:00 PM	63.27	32.72	60
59	12:30:00 PM	64.74	24.24	43
60	12:45:00 PM	65.68	16.14	28
61	1:00:00 PM	66.23	7.59	13
62	1:15:00 PM	66.39	-1.17	-2
63	1:13:00 PM	66.39	0.00	0
64	1:30:00 PM	66.12	9.90	17
65	1:45:00 PM	65.46	18.35	32
66	2:00:00 PM	64.43	26.31	47
67	2:15:00 PM	63.07	33.67	62
68	2:13:00 PM	63.27	32.72	60
69	2:30:00 PM	61.44	40.37	77
70	2:45:00 PM	59.57	46.45	92
71	3:00:00 PM	57.52	51.94	107
72	3:15:00 PM	55.31	56.90	122
73	3:13:00 PM	55.61	56.27	120
74	3:30:00 PM	52.98	61.42	137
75	3:45:00 PM	50.55	65.54	152
76	4:00:00 PM	48.05	69.34	167
77	4:15:00 PM	45.48	72.87	182
78	4:13:00 PM	45.82	72.41	180
79	4:30:00 PM	42.86	76.16	197
80	4:45:00 PM	40.21	79.26	212
81	5:00:00 PM	37.53	82.20	227
82	5:15:00 PM	34.84	85.01	242
83	5:13:00 PM	35.20	84.64	240
84	5:30:00 PM	32.13	87.71	257
85	5:45:00 PM	29.42	89.67	272
86	6:00:00 PM	26.71	92.88	287
87	6:15:00 PM	24.00	95.38	302
88	6:13:00 PM	24.36	95.05	300
89	6:30:00 PM	21.30	97.83	317
90	6:45:00 PM	18.63	100.27	332
91	7:00:00 PM	15.97	102.69	347
92	7:15:00 PM	13.33	105.11	362
93	7:13:00 PM	13.68	104.78	360
94	7:30:00 PM	10.73	107.53	377
95	7:45:00 PM	8.16	109.98	392
96	8:00:00 PM	5.63	112.45	407
97	8:15:00 PM	3.15	114.95	422
98	8:13:00 PM	3.47	114.62	420
99	8:30:00 PM	0.71	117.50	437
100	8:45:00 PM	-1.67	120.10	452
101	9:00:00 PM	-3.98	122.76	467

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude: 43 Deg. 39 Min. North			43.65
4	longtitude 79 Deg. 23MIN			79.38
5	Declination JUNE 21st			23.44
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		172.00	
14				
15	solar time= S. time +4(lo std-lo loc)+equation of time			
16				
17	**JUNE 21ST**			
18	SUNRISE 5:36 AM SUNSET 9:02 PM DST			
19				
20	TIME DST	ALTITUDE	AZIMUTH	MIN-NOON
21	5:00:00 AM	-5.96	130.72	499
22	5:15:00 AM	-3.86	127.98	484
23	5:19:00 AM	-3.29	127.26	480
24	5:30:00 AM	-1.68	125.31	469
25	5:45:00 AM	0.57	122.71	454

	A	B	C	D
26	6:00:00 AM	2.88	120.16	439
27	6:15:00 AM	5.26	117.67	424
28	6:19:00 AM	5.90	117.01	420
29	6:30:00 AM	7.68	115.22	409
30	6:45:00 AM	10.16	112.80	394
31	7:00:00 AM	12.69	110.41	379
32	7:15:00 AM	15.25	108.05	364
33	7:19:00 AM	15.94	107.42	360
34	7:30:00 AM	17.84	105.69	349
35	7:45:00 AM	20.47	103.34	334
36	8:00:00 AM	23.12	100.98	319
37	8:15:00 AM	25.80	98.60	304
38	8:19:00 AM	26.51	97.96	300
39	8:30:00 AM	28.49	96.19	289
40	8:45:00 AM	31.19	93.74	274
41	9:00:00 AM	33.90	88.78	259
42	9:15:00 AM	36.61	88.63	244
43	9:19:00 AM	37.34	87.92	240
44	9:30:00 AM	39.32	85.94	229
45	9:45:00 AM	42.02	83.13	214
46	10:00:00 AM	44.71	80.17	199
47	10:15:00 AM	47.37	77.02	184
48	10:19:00 AM	48.07	76.15	180
49	10:30:00 AM	49.99	73.65	169
50	10:45:00 AM	52.57	70.01	154
51	11:00:00 AM	55.09	66.03	139
52	11:15:00 AM	57.52	61.65	124
53	11:19:00 AM	58.16	60.40	120
54	11:30:00 AM	59.85	56.77	109
55	11:45:00 AM	62.05	51.32	94
56	12:00:00 PM	64.08	45.17	79
57	12:15:00 PM	65.88	38.24	64
58	12:19:00 PM	66.32	36.25	60
59	12:30:00 PM	67.42	30.46	49
60	12:45:00 PM	68.61	21.83	34
61	1:00:00 PM	69.42	12.48	19
62	1:15:00 PM	69.77	2.85	4
63	1:19:00 PM	69.79	0.00	0
64	1:30:00 PM	69.66	7.26	11
65	1:45:00 PM	69.09	16.92	26
66	2:00:00 PM	68.10	25.96	41
67	2:15:00 PM	66.74	34.20	56
68	2:19:00 PM	66.32	36.25	60
69	2:30:00 PM	65.07	41.58	71
70	2:45:00 PM	63.16	48.13	86
71	3:00:00 PM	61.05	53.94	101
72	3:15:00 PM	58.78	59.11	116
73	3:19:00 PM	58.16	60.40	120
74	3:30:00 PM	56.40	63.75	131
75	3:45:00 PM	53.92	67.93	146
76	4:00:00 PM	51.38	71.75	161
77	4:15:00 PM	48.77	75.26	176
78	4:19:00 PM	48.07	76.15	180
79	4:30:00 PM	46.13	78.52	191
80	4:45:00 PM	43.46	81.57	206
81	5:00:00 PM	40.77	84.48	221
82	5:15:00 PM	38.06	87.21	236
83	5:19:00 PM	37.34	87.92	240
84	5:30:00 PM	35.35	89.85	251
85	5:45:00 PM	32.64	92.40	266
86	6:00:00 PM	29.93	94.89	281
87	6:15:00 PM	27.23	97.32	296
88	6:19:00 PM	26.51	97.96	300
89	6:30:00 PM	24.55	99.71	311
90	6:45:00 PM	21.88	102.08	326
91	7:00:00 PM	19.24	104.44	341
92	7:15:00 PM	16.63	106.79	356
93	7:19:00 PM	15.94	107.42	360
94	7:30:00 PM	14.05	109.15	371
95	7:45:00 PM	11.50	111.52	386
96	8:00:00 PM	9.00	113.92	401
97	8:15:00 PM	6.54	116.35	416
98	8:19:00 PM	5.90	117.01	420
99	8:30:00 PM	4.14	118.83	431
100	8:45:00 PM	1.79	121.34	446
101	9:00:00 PM	-0.49	123.92	461

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude 43 Deg 39 Min North			43.65
4	longitude 79 Deg 23MIN			79.38
5	Declination JULY 21st			20.61
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		202.00	
14				
15	solar time= S. time +4(lo std-lo loc)+equation of time			
16				
17	**JULY 21ST**			
18	SUNRISE 5:54 AM SUNSET 8:53 PM DST			
19				
20	TIME DST	ALTITUDE	AZIMUTH	MIN-NOON
21	5:00:00 AM	-8.79	128.77	503
22	5:15:00 AM	-6.66	126.95	488
23	5:23:00 AM	-5.49	125.48	480
24	5:30:00 AM	-4.43	124.21	473
25	5:45:00 AM	-2.17	121.53	458
26	6:00:00 AM	0.17	118.92	443
27	6:15:00 AM	2.56	116.36	428
28	6:23:00 AM	3.88	115.02	420
29	6:30:00 AM	5.03	113.85	413
30	6:45:00 AM	7.54	111.38	398
31	7:00:00 AM	10.09	108.93	383
32	7:15:00 AM	12.67	106.51	368
33	7:23:00 AM	14.06	105.22	360
34	7:30:00 AM	15.29	104.10	353
35	7:45:00 AM	17.93	101.69	338
36	8:00:00 AM	20.60	99.27	323
37	8:15:00 AM	23.29	96.84	308
38	8:23:00 AM	24.72	95.53	300
39	8:30:00 AM	25.99	94.37	293
40	8:45:00 AM	28.70	91.86	278
41	9:00:00 AM	31.41	89.28	263
42	9:15:00 AM	34.12	86.63	248
43	9:23:00 AM	35.56	85.18	240
44	9:30:00 AM	36.82	83.88	233
45	9:45:00 AM	39.51	81.02	218
46	10:00:00 AM	42.18	78.00	203
47	10:15:00 AM	44.82	74.81	188
48	10:23:00 AM	46.21	73.02	180
49	10:30:00 AM	47.41	71.40	173
50	10:45:00 AM	49.96	67.73	158
51	11:00:00 AM	52.43	63.75	143
52	11:15:00 AM	54.82	59.41	128
53	11:23:00 AM	56.05	56.92	120
54	11:30:00 AM	57.09	54.64	113
55	11:45:00 AM	59.23	49.36	98
56	12:00:00 PM	61.20	43.50	83
57	12:15:00 PM	62.95	37.00	68
58	12:23:00 PM	63.79	33.26	60
59	12:30:00 PM	64.45	29.83	53
60	12:45:00 PM	65.64	21.99	38
61	1:00:00 PM	66.47	13.58	23
62	1:15:00 PM	66.90	4.78	8
63	1:23:00 PM	66.96	0.00	0
64	1:30:00 PM	66.91	4.18	7
65	1:45:00 PM	66.51	13.01	22
66	2:00:00 PM	65.70	21.45	37
67	2:15:00 PM	64.54	29.33	52
68	2:23:00 PM	63.79	33.26	60
69	2:30:00 PM	63.06	36.54	67
70	2:45:00 PM	61.32	43.09	82
71	3:00:00 PM	59.37	48.98	97
72	3:15:00 PM	57.24	54.30	112
73	3:23:00 PM	56.05	56.92	120
74	3:30:00 PM	54.97	59.11	127
75	3:45:00 PM	52.59	63.48	142
76	4:00:00 PM	50.12	67.47	157
77	4:15:00 PM	47.59	71.16	172
78	4:23:00 PM	46.21	73.02	180
79	4:30:00 PM	44.99	74.58	187
80	4:45:00 PM	42.36	77.79	202
81	5:00:00 PM	39.69	80.82	217
82	5:15:00 PM	37.00	83.70	232
83	5:23:00 PM	35.56	85.18	240
84	5:30:00 PM	34.30	86.45	247
85	5:45:00 PM	31.59	89.11	262
86	6:00:00 PM	28.88	88.31	277
87	6:15:00 PM	26.17	94.20	292
88	6:23:00 PM	24.72	95.53	300
89	6:30:00 PM	23.47	96.67	307
90	6:45:00 PM	20.78	99.11	322
91	7:00:00 PM	18.11	101.53	337
92	7:15:00 PM	15.48	103.94	352
93	7:23:00 PM	14.06	105.22	360
94	7:30:00 PM	12.84	106.35	367
95	7:45:00 PM	10.26	108.77	382
96	8:00:00 PM	7.71	111.21	397
97	8:15:00 PM	5.20	113.68	412
98	8:23:00 PM	3.88	115.02	420
99	8:30:00 PM	2.74	116.18	427
100	8:45:00 PM	0.33	118.73	442
101	9:00:00 PM	-2.02	121.36	457

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude 43 Deg 39 Min North			43.65
4	longitude 79 Deg 23MIN			79.38
5	Declination august 21st			12.35
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		233.00	
14				
15	solar time= S. time +4(lo std-lo loc)+equation of time			
16				
17	**AUGUST 21ST**			
18	SUNRISE 6:27 AM SUNSET 8:14 PM DST			
19				
20	TIME DST	ALTITUDE	AZIMUTH	MIN-NOON
21	5:00:00 AM	-14.94	124.09	500
22	5:15:00 AM	-12.65	121.14	485
23	5:20:00 AM	-11.88	120.18	480
24	5:30:00 AM	-10.30	118.28	470
25	5:45:00 AM	-7.88	115.49	455
26	6:00:00 AM	-5.40	112.77	440
27	6:15:00 AM	-2.88	110.11	425
28	6:20:00 AM	-2.02	109.24	420
29	6:30:00 AM	-0.31	107.50	410
30	6:45:00 AM	2.30	104.92	395
31	7:00:00 AM	4.94	102.38	380
32	7:15:00 AM	7.60	99.84	365
33	7:20:00 AM	8.49	99.00	360
34	7:30:00 AM	10.28	97.32	350
35	7:45:00 AM	12.98	94.79	335
36	8:00:00 AM	15.69	92.24	320
37	8:15:00 AM	18.40	89.67	305
38	8:20:00 AM	19.30	88.80	300
39	8:30:00 AM	21.11	87.05	290
40	8:45:00 AM	23.82	84.38	275
41	9:00:00 AM	26.51	81.63	260
42	9:15:00 AM	29.18	78.80	245
43	9:20:00 AM	30.07	77.83	240
44	9:30:00 AM	31.83	75.86	230
45	9:45:00 AM	34.44	72.79	215
46	10:00:00 AM	37.01	69.58	200
47	10:15:00 AM	39.52	66.18	185
48	10:20:00 AM	40.35	65.00	180
49	10:30:00 AM	41.97	62.58	170
50	10:45:00 AM	44.34	58.75	155

	A	B	C	D
51	11:00:00 AM	46.80	54.84	140
52	11:15:00 AM	48.76	50.24	125
53	11:20:00 AM	49.44	48.69	120
54	11:30:00 AM	50.77	45.50	110
55	11:45:00 AM	52.62	40.39	95
56	12:00:00 PM	54.28	34.90	80
57	12:15:00 PM	55.71	29.03	65
58	12:20:00 PM	56.14	26.98	60
59	12:30:00 PM	56.90	22.78	50
60	12:45:00 PM	57.80	16.19	35
61	1:00:00 PM	58.40	9.35	20
62	1:15:00 PM	58.68	2.35	5
63	1:20:00 PM	58.70	0.00	0
64	1:30:00 PM	58.63	4.69	10
65	1:45:00 PM	58.24	11.68	25
66	2:00:00 PM	57.54	18.42	40
67	2:15:00 PM	56.53	24.90	55
68	2:20:00 PM	56.14	26.98	60
69	2:30:00 PM	55.28	31.03	70
70	2:45:00 PM	53.75	36.78	85
71	3:00:00 PM	52.02	42.13	100
72	3:15:00 PM	50.11	47.11	115
73	3:20:00 PM	49.44	48.69	120
74	3:30:00 PM	48.05	51.74	130
75	3:45:00 PM	45.86	56.04	145
76	4:00:00 PM	43.56	60.05	160
77	4:15:00 PM	41.16	63.81	175
78	4:20:00 PM	40.35	65.00	180
79	4:30:00 PM	38.69	67.33	190
80	4:45:00 PM	36.16	70.67	205
81	5:00:00 PM	33.58	73.83	220
82	5:15:00 PM	30.95	76.85	235
83	5:20:00 PM	30.07	77.83	240
84	5:30:00 PM	28.29	79.76	250
85	5:45:00 PM	25.61	82.56	265
86	6:00:00 PM	22.92	85.26	280
87	6:15:00 PM	20.21	87.93	295
88	6:20:00 PM	19.30	88.80	300
89	6:30:00 PM	17.49	89.47	310
90	6:45:00 PM	14.78	93.09	325
91	7:00:00 PM	12.08	95.63	340
92	7:15:00 PM	9.38	98.16	355
93	7:20:00 PM	8.49	99.00	360
94	7:30:00 PM	6.71	100.69	370
95	7:45:00 PM	4.05	103.22	385
96	8:00:00 PM	1.43	105.78	400
97	8:15:00 PM	-1.17	108.37	415
98	8:20:00 PM	-2.02	109.24	420
99	8:30:00 PM	-3.72	110.99	430
100	8:45:00 PM	-6.23	113.67	445
101	9:00:00 PM	-8.69	116.41	460

	A	B	C	D
1	SOLAR ANGLES TORONTO			
2				
3	Latitude: 43 Deg. 39 Min. North			43.65
4	longitude 79 Deg. 23MIN			79.38
5	Declination SEPTEMBER 21st			0.99
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (-180 over 90 deg.)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		264.00	
14				
15	solar time= St. time +4(lo std-lo loc)+equation of time			
16				
17	SEPTEMBER 21ST			
18	SUNRISE 7:09 AM SUNSET 7:18 PM DST			
19				
20	TIME DST	ALTITUDE	AZIMUTH	MIN-NOON
21	5:00:00 AM	-22.86	115.47	495
22	5:09:00 AM	-21.47	113.64	486
23	5:15:00 AM	-20.48	112.44	480
24	5:30:00 AM	-17.94	109.51	465
25	5:45:00 AM	-15.36	106.67	450

	A	B	C	D
26	6:00:00 AM	-12.75	103.90	435
27	6:09:00 AM	-11.16	102.27	426
28	6:15:00 AM	-10.10	101.19	420
29	6:30:00 AM	-7.42	98.53	405
30	6:45:00 AM	-4.73	95.91	390
31	7:00:00 AM	-2.03	93.31	375
32	7:09:00 AM	-0.40	88.25	366
33	7:15:00 AM	0.68	89.28	360
34	7:30:00 AM	3.40	88.13	345
35	7:45:00 AM	6.11	85.53	330
36	8:00:00 AM	8.80	82.90	315
37	8:09:00 AM	10.42	81.31	306
38	8:15:00 AM	11.49	80.24	300
39	8:30:00 AM	14.15	77.53	285
40	8:45:00 AM	16.79	74.76	270
41	9:00:00 AM	19.38	71.92	255
42	9:09:00 AM	20.92	70.17	246
43	9:15:00 AM	21.94	68.99	240
44	9:30:00 AM	24.45	65.95	225
45	9:45:00 AM	26.89	62.80	210
46	10:00:00 AM	29.27	59.51	195
47	10:09:00 AM	30.66	57.47	186
48	10:15:00 AM	31.57	56.08	180
49	10:30:00 AM	33.77	52.47	165
50	10:45:00 AM	35.87	48.68	150
51	11:00:00 AM	37.84	44.70	135
52	11:09:00 AM	38.96	42.21	126
53	11:15:00 AM	39.68	40.51	120
54	11:30:00 AM	41.36	36.10	105
55	11:45:00 AM	42.87	31.47	90
56	12:00:00 PM	44.19	26.63	75
57	12:09:00 PM	44.88	23.62	66
58	12:15:00 PM	45.29	21.58	60
59	12:30:00 PM	46.18	16.36	45
60	12:45:00 PM	46.82	10.99	30
61	1:00:00 PM	47.21	5.52	15
62	1:09:00 PM	47.32	2.21	6
63	1:15:00 PM	47.34	0.00	0
64	1:30:00 PM	47.21	5.52	15
65	1:45:00 PM	46.82	10.99	30
66	2:00:00 PM	46.18	16.36	45
67	2:09:00 PM	45.68	19.52	54
68	2:15:00 PM	45.29	21.58	60
69	2:30:00 PM	44.19	26.63	75
70	2:45:00 PM	42.87	31.47	90
71	3:00:00 PM	41.36	36.10	105
72	3:09:00 PM	40.37	38.77	114
73	3:15:00 PM	39.68	40.51	120
74	3:30:00 PM	37.84	44.70	135
75	3:45:00 PM	35.87	48.68	150
76	4:00:00 PM	33.77	52.47	165
77	4:09:00 PM	32.46	54.66	174
78	4:15:00 PM	31.57	56.08	180
79	4:30:00 PM	29.27	59.51	195
80	4:45:00 PM	26.89	62.80	210
81	5:00:00 PM	24.45	65.95	225
82	5:09:00 PM	22.95	67.79	234
83	5:15:00 PM	21.94	68.99	240
84	5:30:00 PM	19.38	71.92	255
85	5:45:00 PM	16.79	74.76	270
86	6:00:00 PM	14.15	77.53	285
87	6:09:00 PM	12.56	79.16	294
88	6:15:00 PM	11.49	80.24	300
89	6:30:00 PM	8.80	82.90	315
90	6:45:00 PM	6.11	85.53	330
91	7:00:00 PM	3.40	88.13	345
92	7:09:00 PM	1.77	89.68	354
93	7:15:00 PM	0.68	89.28	360
94	7:30:00 PM	-2.03	93.31	375
95	7:45:00 PM	-4.73	95.91	390
96	8:00:00 PM	-7.42	98.53	405
97	8:09:00 PM	-9.03	100.12	414
98	8:15:00 PM	-10.10	101.19	420
99	8:30:00 PM	-12.75	103.90	435
100	8:45:00 PM	-15.36	106.67	450
101	9:00:00 PM	-17.94	109.51	465

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude 43 Deg 39 Min North			43.65
4	longitude 79 Deg 23MIN			79.38
5	Declination OCTOBER 21st			-10.44
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (180 over 90 deg)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		294.00	
14				
15	solar time= S. time +4(lo std to loc)+equation of time			
16				
17	**OCTOBER 21ST**			
18	SUNRISE 6:38 AM, SUNSET 5:27 PM EST			
19				
20	TIME EST	ALTITUDE	AZIMUTH	MIN NOON
21	4:00:00 AM	-28.92	103.94	481.00
22	4:01:00 AM	-28.74	103.74	480.00
23	4:15:00 AM	-26.27	101.04	466.00
24	4:30:00 AM	-23.58	98.24	451.00
25	4:45:00 AM	-20.90	95.52	436.00
26	5:00:00 AM	-18.19	92.88	421.00
27	5:01:00 AM	-18.01	92.71	420.00
28	5:15:00 AM	-15.48	89.75	406.00
29	5:30:00 AM	-12.77	87.67	391.00
30	5:45:00 AM	-10.08	85.12	376.00
31	6:00:00 AM	-7.38	82.58	361.00
32	6:01:00 AM	-7.19	82.41	360.00
33	6:15:00 AM	-4.68	80.03	346.00
34	6:30:00 AM	-2.02	77.47	331.00
35	6:45:00 AM	0.61	74.89	316.00
36	7:00:00 AM	3.22	72.28	301.00
37	7:01:00 AM	3.39	72.10	300.00
38	7:15:00 AM	5.78	69.62	286.00
39	7:30:00 AM	8.30	66.90	271.00
40	7:45:00 AM	10.77	64.13	256.00
41	8:00:00 AM	13.18	61.27	241.00
42	8:01:00 AM	13.34	61.08	240.00
43	8:15:00 AM	15.53	58.34	226.00
44	8:30:00 AM	17.80	55.30	211.00
45	8:45:00 AM	19.98	52.16	196.00
46	9:00:00 AM	22.08	48.91	181.00
47	9:01:00 AM	22.22	48.69	180.00
48	9:15:00 AM	24.17	45.54	166.00
49	9:30:00 AM	25.95	42.04	151.00
50	9:45:00 AM	27.70	38.40	136.00
51	10:00:00 AM	29.32	34.62	121.00
52	10:01:00 AM	29.42	34.37	120.00
53	10:15:00 AM	30.78	30.71	106.00
54	10:30:00 AM	32.08	26.87	91.00
55	10:45:00 AM	33.21	22.50	76.00
56	11:00:00 AM	34.16	18.22	61.00
57	11:01:00 AM	34.21	17.93	60.00
58	11:15:00 AM	34.91	13.83	46.00
59	11:30:00 AM	35.45	9.37	31.00
60	11:45:00 AM	35.79	4.85	16.00
61	12:00:00 PM	35.91	0.30	1.00
62	12:01:00 PM	35.91	0.00	0.00
63	12:15:00 PM	35.82	4.25	14.00
64	12:30:00 PM	35.51	8.77	29.00
65	12:45:00 PM	34.99	13.24	44.00
66	1:00:00 PM	34.27	17.64	59.00
67	1:01:00 PM	34.21	17.93	60.00
68	1:15:00 PM	33.35	21.94	74.00
69	1:30:00 PM	32.24	26.12	89.00
70	1:45:00 PM	30.96	30.18	104.00
71	2:00:00 PM	29.52	34.11	119.00
72	2:01:00 PM	29.42	34.37	120.00
73	2:15:00 PM	27.92	37.90	134.00
74	2:30:00 PM	26.19	41.58	149.00
75	2:45:00 PM	24.33	45.08	164.00
76	3:00:00 PM	22.35	48.47	179.00
77	3:01:00 PM	22.22	48.69	180.00
78	3:15:00 PM	20.27	51.74	194.00
79	3:30:00 PM	18.09	54.89	209.00
80	3:45:00 PM	15.83	57.94	224.00
81	4:00:00 PM	13.50	60.89	239.00
82	4:01:00 PM	13.34	61.08	240.00
83	4:15:00 PM	11.09	63.75	254.00
84	4:30:00 PM	8.63	66.54	269.00
85	4:45:00 PM	6.12	69.26	284.00
86	5:00:00 PM	3.56	71.92	299.00
87	5:01:00 PM	3.39	72.10	300.00
88	5:15:00 PM	0.96	74.54	314.00
89	5:30:00 PM	-1.67	77.13	329.00
90	5:45:00 PM	-4.33	79.69	344.00
91	6:00:00 PM	-7.01	82.24	359.00
92	6:01:00 PM	-7.19	82.41	360.00
93	6:15:00 PM	-9.70	84.78	374.00
94	6:30:00 PM	-12.41	87.33	389.00
95	6:45:00 PM	-15.12	89.91	404.00
96	7:00:00 PM	-17.83	92.49	419.00
97	7:01:00 PM	-18.01	92.69	420.00
98	7:15:00 PM	-20.54	95.16	434.00
99	7:30:00 PM	-23.24	97.86	449.00
100	7:45:00 PM	-25.91	100.67	464.00

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude 43 Deg 39 Min North			43.65
4	longitude 79 Deg 23MIN			79.38
5	Declination NOVEMBER 21st			-19.75
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (180 over 90 deg)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		325.00	
14				
15	solar time= S. time +4(lo std to loc)+equation of time			
16				
17	**NOVEMBER 21ST**			
18	SUNRISE 7:18 AM, SUNSET 4:49 PM EST			
19				
20	TIME EST	ALTITUDE	AZIMUTH	MIN NOON
21	4:00:00 AM	-35.73	98.37	484.00
22	4:04:00 AM	-35.01	95.83	480.00
23	4:15:00 AM	-33.03	93.62	469.00
24	4:30:00 AM	-30.32	89.03	454.00
25	4:45:00 AM	-27.60	88.38	439.00
26	5:00:00 AM	-24.90	85.86	424.00
27	5:04:00 AM	-24.17	85.20	420.00
28	5:15:00 AM	-22.19	83.38	409.00
29	5:30:00 AM	-19.51	80.94	394.00
30	5:45:00 AM	-16.84	78.51	379.00
31	6:00:00 AM	-14.19	76.08	364.00
32	6:04:00 AM	-13.49	75.44	360.00
33	6:15:00 AM	-11.57	73.66	349.00
34	6:30:00 AM	-8.98	71.22	334.00
35	6:45:00 AM	-6.43	68.75	319.00
36	7:00:00 AM	-3.93	66.26	304.00
37	7:04:00 AM	-3.27	65.59	300.00
38	7:15:00 AM	-1.47	63.72	289.00
39	7:30:00 AM	0.94	61.14	274.00
40	7:45:00 AM	3.26	58.50	259.00
41	8:00:00 AM	5.56	55.80	244.00
42	8:04:00 AM	6.16	55.07	240.00
43	8:15:00 AM	7.77	53.02	229.00
44	8:30:00 AM	9.89	50.17	214.00
45	8:45:00 AM	11.93	47.24	199.00
46	9:00:00 AM	13.88	44.22	184.00
47	9:04:00 AM	14.38	43.40	180.00
48	9:15:00 AM	15.71	41.10	169.00
49	9:30:00 AM	17.44	37.89	154.00
50	9:45:00 AM	19.04	34.38	139.00

	A	B	C	D
51	10:00:00 AM	20.52	31.17	124.00
52	10:04:00 AM	20.89	30.24	120.00
53	10:15:00 AM	21.85	27.68	109.00
54	10:30:00 AM	23.03	24.07	94.00
55	10:45:00 AM	24.06	20.38	79.00
56	11:00:00 AM	24.92	16.62	64.00
57	11:04:00 AM	25.12	15.61	60.00
58	11:15:00 AM	25.61	12.79	49.00
59	11:30:00 AM	26.12	8.91	34.00
60	11:45:00 AM	26.45	4.99	19.00
61	12:00:00 PM	26.59	1.05	4.00
62	12:04:00 PM	26.60	0.00	0.00
63	12:15:00 PM	26.55	2.85	11.00
64	12:30:00 PM	26.32	6.83	26.00
65	12:45:00 PM	25.91	10.73	41.00
66	1:00:00 PM	25.31	14.59	56.00
67	1:04:00 PM	25.12	15.61	60.00
68	1:15:00 PM	24.54	18.39	71.00
69	1:30:00 PM	23.60	22.11	86.00
70	1:45:00 PM	22.50	25.76	101.00
71	2:00:00 PM	21.25	29.31	116.00
72	2:04:00 PM	20.89	30.24	120.00
73	2:15:00 PM	19.85	32.77	131.00
74	2:30:00 PM	18.31	36.14	146.00
75	2:45:00 PM	16.65	39.40	161.00
76	3:00:00 PM	14.87	42.57	176.00
77	3:04:00 PM	14.38	43.40	180.00
78	3:15:00 PM	12.98	45.64	191.00
79	3:30:00 PM	10.99	48.62	206.00
80	3:45:00 PM	8.91	51.51	221.00
81	4:00:00 PM	6.75	54.33	236.00
82	4:04:00 PM	6.16	55.07	240.00
83	4:15:00 PM	4.51	57.07	251.00
84	4:30:00 PM	2.20	59.74	266.00
85	4:45:00 PM	-0.18	62.35	281.00
86	5:00:00 PM	-2.61	64.91	296.00
87	5:04:00 PM	-3.27	65.58	300.00
88	5:15:00 PM	-5.09	67.43	311.00
89	5:30:00 PM	-7.63	69.91	326.00
90	5:45:00 PM	-10.19	72.38	341.00
91	6:00:00 PM	-12.79	74.79	356.00
92	6:04:00 PM	-13.49	75.44	360.00
93	6:15:00 PM	-15.42	77.21	371.00
94	6:30:00 PM	-18.08	79.64	386.00
95	6:45:00 PM	-20.76	82.08	401.00
96	7:00:00 PM	-23.45	84.54	416.00
97	7:04:00 PM	-24.17	85.20	420.00
98	7:15:00 PM	-26.16	87.03	431.00
99	7:30:00 PM	-28.87	89.58	446.00
100	7:45:00 PM	-31.58	92.19	461.00

	A	B	C	D
1	**SOLAR ANGLES TORONTO**			
2				
3	Latitude 43 Deg. 39 Min. North			43.65
4	longitude 79 Deg. 23MIN			79.38
5	Declination DECEMBER 21st			23.43
6				
7				
8	sin Alt = cos L cos d cos h + sin L sin d			
9	sin Az = cos d sin h / cos Alt (180 over 90 deg)			
10				
11	Equation of time= 9.87sin2b-7.53cosb-1.5sinb			
12	b=360/364*(n-81)			
13	Day of Year (n)		355.00	
14				
15	solar time= S. time +4(lo std-lo loc)+equation of time			
16				
17	**DECEMBER 21ST**			
18	SUNRISE 7:47 AM, SUNSET 4:43 PM EST			
19				
20	TIME EST	ALTITUDE	AZIMUTH	MIN NOON
21	4:00:00 AM	-40.22	94.99	496.00
22	4:15:00 AM	-37.61	92.26	481.00
23	4:28:00 AM	-35.16	89.99	468.00
24	4:30:00 AM	-34.80	89.64	466.00
25	4:45:00 AM	-32.06	87.10	451.00

	A	B	C	D
26	5:00:00 AM	-29.39	84.63	433.00
27	5:15:00 AM	-26.89	82.21	421.00
28	5:28:00 AM	-24.39	80.14	408.00
29	5:30:00 AM	-24.01	79.82	406.00
30	5:45:00 AM	-21.35	77.46	391.00
31	6:00:00 AM	-18.71	75.10	376.00
32	6:15:00 AM	-16.10	72.75	361.00
33	6:28:00 AM	-13.87	70.70	348.00
34	6:30:00 AM	-13.53	70.39	346.00
35	6:45:00 AM	-10.99	68.01	331.00
36	7:00:00 AM	-8.50	65.60	316.00
37	7:15:00 AM	-6.05	63.16	301.00
38	7:28:00 AM	-3.97	61.01	288.00
39	7:30:00 AM	-3.66	60.68	286.00
40	7:45:00 AM	-1.32	58.15	271.00
41	8:00:00 AM	0.95	55.57	256.00
42	8:15:00 AM	3.15	52.92	241.00
43	8:28:00 AM	5.00	50.58	228.00
44	8:30:00 AM	5.28	50.21	226.00
45	8:45:00 AM	7.32	47.42	211.00
46	9:00:00 AM	9.27	44.56	196.00
47	9:15:00 AM	11.12	41.61	181.00
48	9:28:00 AM	12.65	38.99	168.00
49	9:30:00 AM	12.87	38.58	166.00
50	9:45:00 AM	14.51	35.47	151.00
51	10:00:00 AM	16.02	32.26	136.00
52	10:15:00 AM	17.40	28.97	121.00
53	10:28:00 AM	18.49	26.05	108.00
54	10:30:00 AM	18.64	25.60	106.00
55	10:45:00 AM	19.74	22.15	91.00
56	11:00:00 AM	20.69	18.62	76.00
57	11:15:00 AM	21.47	15.03	61.00
58	11:28:00 AM	22.02	11.88	48.00
59	11:30:00 AM	22.09	11.39	46.00
60	11:45:00 AM	22.54	7.70	31.00
61	12:00:00 PM	22.82	3.98	16.00
62	12:15:00 PM	22.92	0.25	1.00
63	12:18:00 PM	22.92	0.00	3.00
64	12:30:00 PM	22.84	3.48	14.00
65	12:45:00 PM	22.83	3.73	15.00
66	1:00:00 PM	22.57	7.45	30.00
67	1:15:00 PM	22.13	11.14	45.00
68	1:28:00 PM	21.61	14.31	58.00
69	1:30:00 PM	21.52	14.79	60.00
70	1:45:00 PM	20.75	18.38	75.00
71	2:00:00 PM	19.81	21.91	90.00
72	2:15:00 PM	18.72	25.37	105.00
73	2:28:00 PM	17.66	28.31	118.00
74	2:30:00 PM	17.49	28.75	120.00
75	2:45:00 PM	16.11	32.05	135.00
76	3:00:00 PM	14.61	35.26	150.00
77	3:15:00 PM	12.98	38.38	165.00
78	3:28:00 PM	11.48	41.01	178.00
79	3:30:00 PM	11.24	41.41	180.00
80	3:45:00 PM	9.40	44.37	195.00
81	4:00:00 PM	7.45	47.23	210.00
82	4:15:00 PM	5.42	50.03	225.00
83	4:28:00 PM	3.58	52.39	238.00
84	4:30:00 PM	3.30	52.74	240.00
85	4:45:00 PM	1.10	55.39	255.00
86	5:00:00 PM	-1.17	57.98	270.00
87	5:15:00 PM	-3.50	60.51	285.00
88	5:28:00 PM	-5.57	62.67	298.00
89	5:30:00 PM	-5.89	63.00	300.00
90	5:45:00 PM	-8.33	65.44	315.00
91	6:00:00 PM	-10.82	67.85	330.00
92	6:15:00 PM	-13.36	70.23	345.00
93	6:28:00 PM	-15.59	72.28	358.00
94	6:30:00 PM	-15.93	72.59	360.00
95	6:45:00 PM	-18.54	74.94	375.00
96	7:00:00 PM	-21.17	77.30	390.00
97	7:15:00 PM	-23.83	79.66	405.00
98	7:28:00 PM	-26.15	81.73	418.00
99	7:30:00 PM	-26.51	82.05	420.00
100	7:45:00 PM	-29.20	84.47	435.00
101	8:00:00 PM	-31.91	86.94	430.00

Appendix 1.2 Methodology for Wind Tunnel Testing

This section describes the experimental methods used for the wind tunnel tests.

Model-Building

Building models were fabricated out of polystyrene foam. Buildings on Site 1 were modeled at a scale of 1:480, and those on Sites 2 and 3 were modeled at a scale of 1:360. Given the presence of very high buildings on Site 1, a smaller scale was necessary for limiting the overall wind tunnel projected area blockage to less than 10 percent. A 720 m diameter was modeled for Sites 2 and 3, and 960 m for Site 1. Within that diameter, each building was modeled as accurately as possible.

Wind obstructions located further away from the sites were considered part of the general terrain roughness of the site, and they were modeled with blocks as part of the characteristic atmospheric boundary layer in the wind tunnel.

Wind Tunnel Facility

The study was conducted in the Boundary Layer Wind Tunnel (BLWT) located in the Building Science Laboratory in the Department of Architecture, University of California at Berkeley. The interior dimensions of the wind tunnel are 1.5 m (5 ft) high and 2.1 m (7 ft) wide, with an overall length of 19.5 m (64 ft). As shown in Figs. 4.3 and 4.4, beginning with the bellmouth entry, the first 12.8 meters (42 ft) of the BLWT comprise the flow-processing section in which a combination of turbulence-generating devices and rough objects covering the wind tunnel floor are used to simulate the characteristic surface roughness of the upwind terrain relative to the scale of the building model. Immediately beyond the flow-processing section is the test area, 3.7 m (12 ft) in length, in which the scale models are placed on a 2-meter-diameter (6.6 ft) turntable for testing. A variable-speed fan is located downwind of the test area. The data acquisition room is located adjacent to the test area.

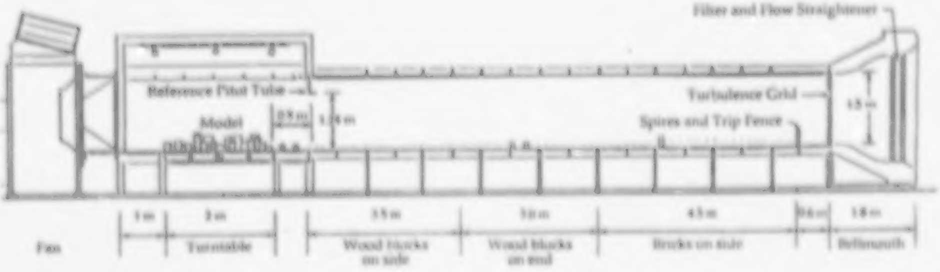


FIGURE 2: Boundary Layer Wind Tunnel Configuration

Fig A1.1 Boundary Layer Wind Tunnel

Air velocity measurements, used to determine pedestrian-level wind speeds and to characterize the boundary layer profiles of velocity and turbulence intensity, were made with a Thermo Systems, Inc. (TSI), Model 1053B anemometer attached to a TSI Model 1266 rugged metal-clad probe. Probe calibrations were performed with a TSI Model 1125 calibrator using an MKS Instruments, Inc., Model 220BD differential pressure transducer. An IBM PC/AT-based data acquisition system was used to record the anemometer measurements and to perform the necessary data reduction, analysis, and storage.

The mean freestream velocity at a stationary reference location was monitored with a Dwyer Model 166-12 pitot tube connected to a Validyne Model DP103 differential pressure transducer and Model CD15 sine wave carrier demodulator (signal conditioner). This reference velocity measurement allowed the wind tunnel results to be presented in terms of a velocity ratio, as described in Measurement Procedure and Data Analysis. Flow visualization was performed with an Elven Precision Ltd. smoke-generating system.

Simulation of Atmospheric Boundary Layer

Boundary-layer wind tunnels are used to simulate characteristics of natural wind on a scale equal to that of the model building. The simulated region of interest is known as the atmospheric boundary layer, which corresponds to the gradual increase of wind velocity with height above the ground up to a height where ground-based obstacles, such as buildings, trees, and low hills, cease to affect wind characteristics.

Within the atmospheric boundary layer, the key wind features to be modeled, the vertical distributions of mean wind speed, turbulence intensity, and eddy size are largely determined by surface characteristics upwind of a particular building site.

The variation of wind velocity with height in the lower levels of the atmospheric boundary layer (the region of greatest interest in building-related wind studies) can be represented by the logarithmic velocity profile for a thermally neutral atmosphere.

Equation 1:

$$U(z) = (u^*/k) \ln[(z-d)/z_0]$$

where:

$U(z)$ = mean velocity at height z

u^* = friction velocity

k = von Karman's constant (0.4)

z = height above ground level

z_0 = roughness length

d = displacement height

Terrain types around the selected sites vary depending on the site and wind direction under consideration. For Site 1 and for winds coming from the west through the north and to the east, the terrain is typical of an urban environment, with a large number of high-rise buildings surrounding the site. Where winds come across the lake (i.e. southwest through southeast), the upwind terrain is smooth. For Sites 2 and 3, in the core of the city, the surroundings for all wind directions are typical of suburban to urban terrains.

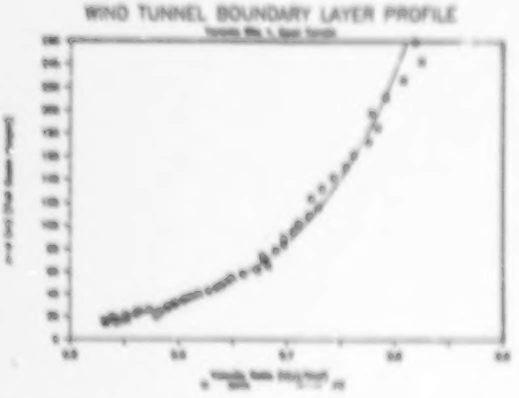


Fig. A1.2

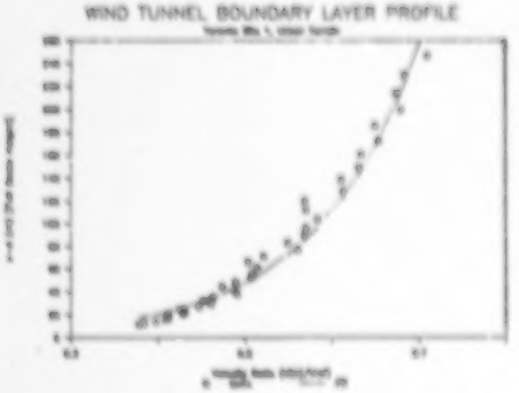


Fig. A1.3

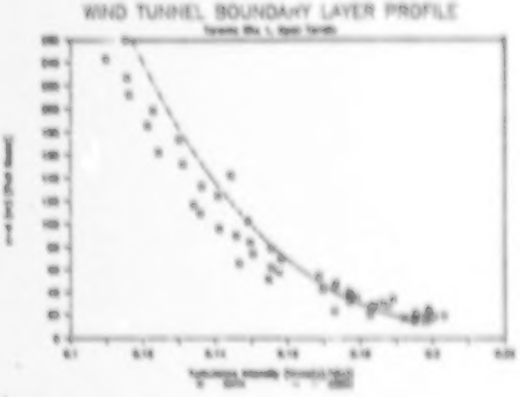


Fig. A1.4

Turbulence intensity is a measure of the magnitude of velocity fluctuations compared to the mean velocity at a point in turbulent flow. Turbulence intensities are always greatest near the ground, where the boundary layer flow interacts with the surface roughness and obstructions, and decreases with increasing height above the ground. Velocity and turbulence intensity profiles were measured in the wind tunnel immediately upwind of the model location in order to document the approach wind conditions. These measured profiles are presented in Figs. A1.2 to A1.7.

Where winds are blowing across the lake and toward Site 1, a fairly open terrain configuration was modeled. In Fig. A1.2, the solid line represents the regression fit ($R^2 = 0.991$) of the measured data to Equation (1) for that case. The fit produced a full-scale roughness length (z_0) of 0.08m for a displacement height (d) of 0m, slightly rougher, but still well within the acceptable range of values described by ESDU [1,2] for that terrain. In Fig. A1.3, the measured turbulence intensities are presented and correspond well to ESDU values for the lower region of the atmospheric boundary layer [2].

For the winds coming over the city, an urban terrain was modeled. Fig A1.4 shows the regression fit (R2 = 0.969) for that profile which gave a full-scale roughness length (z_0) of 0.75 m for a displacement height (d) of 13 m, typical of an urban setup [1,2]. The corresponding turbulence intensity distributions, shown in Fig. A1.5, also correspond well to ESDU-recommended values. This same boundary layer setup was also used for all wind directions on sites 2 and 3. Given the larger scale for these sites (1:360

instead of 1:480), the corresponding full-scale roughness length (z_0) was of 0.55 m for a displacement height (d) of 10m, which falls between the suburban and urban categories as defined by ESDU [1,2]. The plots showing the velocity and turbulence profiles for these two sites are shown in Figs. A1.6 and A1.7.

Measurement Procedure
For each site, 50 to 70 pedestrian-level velocity measurement locations were selected at important pedestrian areas such as walkways or esplanades. For each site, the wind environment was investigated for four different wind directions as described in the Weather Data section: southwest, northwest, west, and east.

With a reference mean velocity of 6.4 m/s, each measurement consisted of simultaneous readings from the anemometer probe positioned at the desired pedestrian-level location, and the reference pitot tube located 1.23 m above the wind tunnel floor and 0.9 m upwind of the front edge of the turntable. The axis of the anemometer probe was positioned vertically in all cases, and its height corresponded to a full-scale height of 2 m. The position of the reference pitot tube was selected to eliminate any interference with simultaneous building model measurements, while providing a stable characteristic reference velocity away from the influence of the building models and ground-level measurements. During each measurement, the two sensors were sampled at a rate of 15 readings per second for a duration of 30 seconds. The collected data was analyzed to produce the quantities of interest: mean velocity, turbulence intensity, and equivalent wind speed.

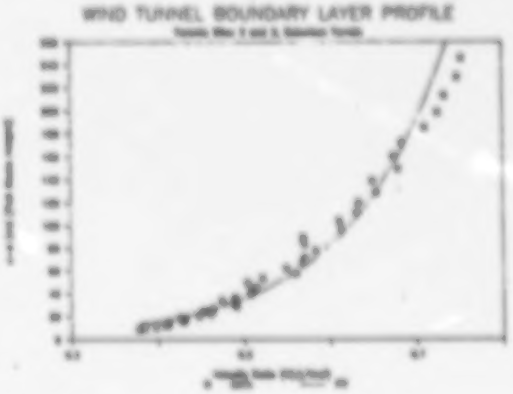


Fig. A1.5

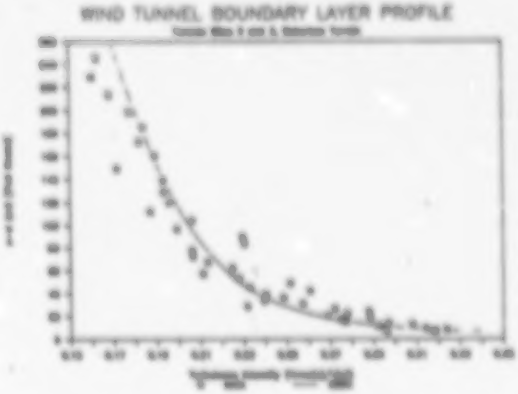


Fig. A1.6

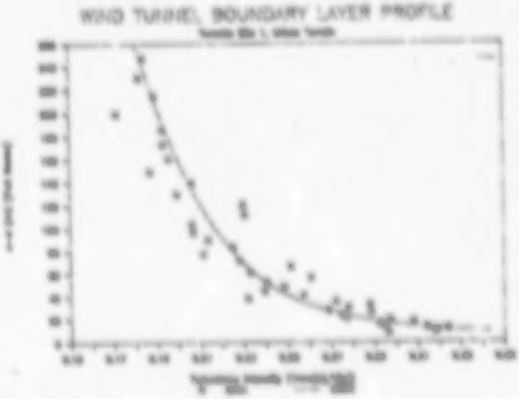


Fig. A1.7

Data Analysis

The San Francisco wind code [5] was used as a guide to determine the acceptability of the measured wind conditions for each site. This wind code is based on wind acceptability criteria defined in terms of equivalent wind speed (EWS). EWS denotes the mean hourly wind speed adjusted to account for the expected turbulence intensity or gustiness at the site. The wind speed limits in the code were developed with an inherent turbulence intensity of 15 percent. When the measured turbulence intensity at a point is greater than 15 percent, the equivalent wind speed is calculated by multiplying the mean velocity at the point by a weighting factor according to the following formula:

Equation 2:

$$\mathbf{EWS = V_m(2*TI + 0.7)}$$

where:

V_m = mean pedestrian-level wind speed

TI = turbulence intensity

For measured turbulence intensities less than 15 percent, EWS is taken to be equal to V_m.

Wind speed data representative of Toronto and vicinity are available from the weather station located at Toronto International Airport at a height of 10 m (33 ft). The collected wind tunnel data was analyzed to determine the empirical relationship between the equivalent wind speed at each selected pedestrian-level location and the mean wind speed at the weather station height. This relationship is expressed in terms of a velocity ratio defined as follows:

Equation 3:

$$\mathbf{Velocity\ Ratio = EWS/Vws = (EWS/V_{pitot})(V_{pitot}/V_{ref})(V_{ref}/V_{ws})}$$

where:

EWS= equivalent wind speed at pedestrian level (m/s), calculated according to Equation 2

V_{ws}= mean velocity at weather station height; 10.0m at full-scale, (m/s)

V_{pitot}= mean velocity at pitot tube (m/s)

V_{ref}= mean velocity measured at 40 cm in the wind tunnel (m/s)

The terrain around the weather station site can be characterized as open, flat country, typical of airports. Since the simulated boundary layer in the wind tunnel was representative of a different terrain, Vws could not be measured directly. The velocity ratio was therefore determined in stages, as indicated in Equation 3. The ratio EWS/Vpitot was measured using a reference pitot tube height of 1.23 m (4.1 ft), as described previously. Since the pitot tube is located above the simulated boundary layer region in the wind tunnel, a separate measurement was used to reference the wind tunnel measurements to a velocity within the modeled boundary layer. For this purpose the anemometer was placed at a height of 40 cm (corresponding to 192m full-scale for Site 1 and 144 m full-scale for Sites 2 and 3) and the ratio, Vpitot/Vref, was measured. Finally, using values from the literature [6] for an open, flat country boundary layer wind velocity profile, the values of the ratio Vref/Vws were estimated according to the logarithmic law. The calculation in Equation 3 assumes that the value Vref remains unchanged between the weather station location and the city. Due to the proximity of the airport to the three sites this is a reasonable approximation.

REFERENCES:

1. Engineering Sciences Data Unit, "Strong winds in the atmospheric boundary layer," Item No. 82026, ESDU, London, 1982.

2. Engineering Sciences Data Unit, "Characteristics of atmospheric turbulence near the ground," Item Nos. 74030, 75001, and 85020, ESDU, London, 1974, 1975, and 1985.

3. Engineering Sciences Data Unit, "Longitudinal turbulence intensities over terrain with roughness changes for flat or hilly sites," Item No. 84030, ESDU, London, 1984.

4. Cook, Nick. "Simulation Techniques for Short Test-Section Wind Tunnels: Roughness, Barrier and Mixing-Device Methods," International Workshop on Wind Tunnel Modeling Criteria and Techniques for Civil Engineering Applications, Timothy A. Reinhold, ed., April 14-16, 1982, pp. II.3-1 - II.3-12.

5. Arens, E., Ballanti, D., Bennett, D., Guldman, S., and White, B. "Developing the San Francisco Wind Ordinance and its Guidelines for Compliance," Building and Environment, Vol. 24, No. 4, 1989, pp. 297-303.

6. Bietry, J., Sacre, C., and Simiu, E. "Mean Wind Profiles and Change of Terrain Roughness," Journal of the Structural Division, ASCE, 104, No. ST10, 1978, pp. 1585-1593.

Appendix 1.3

Thermal Comfort Modeling

Computer models of thermal comfort predict how people will feel when exposed to certain physical conditions. This section will present an overview of the computer model used in this project and outline the assumptions inherent in extending its application to the outdoors.

Six personal and climatological variables affect thermal comfort. These are metabolic rate, clothing level, air temperature, air velocity, mean radiant temperature, and relative humidity. Metabolic rate is measured in watts per square meter of body surface area or 'met' units (58.2 watts per square meter equals 1 'met,' which corresponds to sedentary activity). Clothing insulation is measured in 'clo' units. One 'clo' is the insulation of a relatively heavy suit, including underwear, shirt with long sleeves, trousers, jacket or sweater with long sleeves, heavy socks, and shoes. Mean radiant temperature is an index that integrates radiation from different surfaces surrounding the body according to its size and surface temperature. Since the computer model was originally designed for indoor conditions and does not account for sunlight, we have added an equation to convert the sunlight value to a mean radiant temperature. This equation assumes a standard human, surface area 1.8 square meters and weight 70 kilograms, exposed to diffuse and direct radiation using an average solar elevation of 45 degrees (Arens, Berglund, Gonzales 1986). The computer model assumes a cylindrical human with a core and skin layer and clothing evenly distributed over the cylinder (Gagge, Fobelets, and Berglund, 1986). Before exposure to the environment, the body is thermally neutral and all heat produced internally is liberated to the environment at constant skin temperature. The exposure begins and the model solves a heat balance equation on a minute-by-minute basis for the desired period. At the end of the exposure, the model evaluates the new skin temperature and/or skin-wettedness due to sweating. Years of laboratory studies have provided well-accepted relationships between these physiological measures and indexes of thermal sensation. The model outputs an index (DISC) that incorporates these relationships and provides criteria for evaluating whether a given condition is comfortable. A condition is considered comfortable if DISC is within the limits defined in the ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers) indoor thermal environment standards (ASHRAE, 1981).

In applying the computer model to the city of Toronto, each input variable requires careful evaluation. The first two input parameters, metabolic rate and clothing, are based on our estimates of typical activities and dress for the Toronto population. To estimate metabolic rate most of the year, the Berkeley Team averaged sitting and walking activities (1.3 met), using 0.8 clo for the spring and fall seasons and 0.6 clo for the summer (Fig. A1.8). Naturally, these parameters vary from season to season and for extreme conditions on any particular day. The model accounts for these fluctuations in a manner described below.

The last four parameters, air temperature, air velocity, mean radiant temperature, and relative humidity represent the thermal resistance of clothing ensembles

Clothing ensemble	I_{cl}	
	(m² · °C/W)	(clo)
Nude	0	0
Shorts	0,015	0,1
Typical tropical clothing ensemble: briefs, shorts, open-neck shirt with short sleeves, light socks and sandals	0,045	0,3
Light summer clothing: briefs, long light-weight trousers, open-neck shirt with short sleeves, light socks and shoes	0,08	0,5
Light working ensemble: light underwear, cotton work shirt with long sleeves, work trousers, woollen socks and shoes	0,11	0,7
Typical indoor winter clothing ensemble: underwear, shirt with long sleeves, trousers, jacket or sweater with long sleeves, heavy socks and shoes	0,16	1,0
Heavy traditional European business suit: cotton underwear with long legs and sleeves, shirt, suit including trousers, jacket and waistcoat, woollen socks and heavy shoes	0,23	1,5

Fig. A1.8

environmental conditions people experience. Hourly weather data from the international airport station near Toronto were used as as input to the model. The data is a 'typical meteorological year:' a composite year-long record of hourly values over a year period that are most representative of the long-term climate patterns from month to month. Local street-level air velocity was determined by adjusting hourly airport wind speeds measured at the airport, using the results of the wind tunnel tests. Local mean radiant temperature was determined by adjusting the solar radiation values measured at the airport, by a factor indicating direct sunlight or shade for a particular hour. These conversions are described in detail in the next two sections.

Local wind velocity

As weather data is read from the weather tape each hour, the model uses the wind direction information to select the appropriate wind ratio from a file in order to compute the local wind speed for that hour. The observations on the weather tape were divided into four bins. The boundaries of each bin were selected based on the frequency and strength of winds from the various directions (given in degrees). The boundaries are as follows:

1. Between 303.75 and 11.25: ***Northwest***
2. Between 11.25 and 146.25: ***East***
3. Between 146.25 and 236.25: ***Southwest***
4. Between 236.25 and 303.75 ***West***

Local mean radiant temperature

Mean radiant temperature was calculated for each hour by determining whether a point was in the sun or in the shade during that hour of the day. When in the shade, direct radiation is absent, but the body is exposed to diffuse and reflected radiation from surrounding buildings. If the sunlight analysis indicates that a point is in the shade during a particular hour, the solar radiation level (measured at the airport) is reduced to 25 percent of its original value for the calculation of mean radiant temperature. This relationship is based on empirical measurements of diffuse and reflected radiation in urban surroundings. The calculation of mean radiant temperature from solar radiation value uses the fraction of body surface area exposed to the sun at an average value of 45 degrees altitude, the absorptivities of skin and clothing, and the radiative film coefficient (see Arens, Berglund, Gonzales for details of this calculation).

For each point, for each hour of the year between 8:00 a.m. and 7:00 p.m., the model computes the DISC value predicted for an assumed 20-minute exposure to the outdoors. Each hour's DISC value is compared with the ASHRAE comfort zone, and the fraction of hours above, within, and below the zone are recorded by season. The division of the year into seasons is as follows:

Spring:

April 1 to May 31

Summer:

June 1 to August 31

Fall:

September 1 to October 31

One Winter Month:

January 1 to February 1.

In order to produce realistic results for a variety of conditions, the study team made specific adjustments when conditions fell outside a certain range. For example, if the model predicts DISC values that are too hot, while the air temperature is less than 20 degrees Celsius, it was assumed that people will remain comfortable by removing clothing. The hours before 9:00 a.m. and after 5:00 p.m. in the winter season are not included in the analysis, since these times are generally dark. For the spring and fall seasons, if the air temperature is below 10 degrees Celsius, 0.5 clo was added to the base case of 0.8, an adjustment roughly equivalent to putting on an overcoat. For the summer season, if the air temperature is below 20 degrees Celsius, 0.2 clo was added to the base case of 0.6. In the winter, clothing was increased to 1.5 clo and metabolic rate to 2 met, but a function for wind-chill was not included. Such a function would produce wind discomfort from combinations of very cold temperature and wind, regardless of the human's overall heat balance. Future work might include a wind-chill equation, of the form $H = F(V,T)$, applied on a minute-by-minute basis in the model. However, implementation and testing of this additional equation was beyond the scope of this project. Fine-tuning of the model could offer greater sensitivity to the adjustment in habits that comes with changes in season. A more sensitive model would yield more precise estimates of pedestrian comfort.

Realistic computer modeling of human outdoor comfort often involves making several assumptions about underlying processes. For this study, we have adapted a model developed for indoor environments to outdoor conditions. This adaptation required assumptions about the activities and dress of the population of Toronto and about the uniformity of weather patterns over areas of the city. The research team believes these assumptions are acceptable when the results are applied over large areas of the city.

REFERENCES:

Arens E., Berglund, L., Gonzales, R. 1986, "Thermal comfort under an extended range of environmental conditions", ASHRAE Transactions, Vol. 92, Pt. 1.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 1981, "Standard 55-81, Thermal environmental conditions for human occupancy", Atlanta.

Gagge, A. P., Fobelets, A. P., Berglund, L. 1986, "A standard predictive index of human response to the thermal environment", ASHRAE Transactions, Vol. 92, Pt. 2.

APPENDIX II

Summary of Existing Legislation in Toronto and Other North American Cities.

At the present time, nearly everywhere in North America, much of the planning control for sun access and wind protection lack specificity and are discretionary rather than enforceable under standards.

Toronto's Official Plan contains policy statements that recognize the need for such controls but these are not followed up by firm regulations and standards. Other Canadian cities have similar policies with discretionary implementation. In most cities, major projects are subjected to wind tunnel studies, and the results are used in negotiations with the planning staff. Sunlight access is regulated by specific performance standards in only one city, Calgary, for a very limited area. Ottowa requires specific site studies adjacent to pedestrian areas, while Edmonton requires studies for buildings over 14 m in height. In other Canadian cities, sun access studies are discretionary.

A number of cities in North America, including San Francisco, Boston, and Philadelphia, use a combination of planning controls to guarantee sun access to open spaces including streets.

Canadian Cities

City	Environmental Quality	Type of Regulation
Calgary	Sunlight Access	Performance Standard Selected streets and open spaces are given specific performance standards in the planning legislation.
	Wind-Shelter	Discretionary Review Requirement for larger development projects to conduct wind studies.
Edmonton	Sunlight Access	Discretionary Review For buildings over 14 m in height, a sun shadow impact study is required in the Downtown Area.
	Wind-Shelter	Discretionary Review Wind Impact Statement and Study may be requested by Development Department. No consistent policy with regard to application.
Halifax	Sunlight -Wind	Discretionary Review To date only general statements of planning policy limiting 'significant' impacts on pedestrian areas or parks due to shadowing or wind effects. Definition of 'significant' ambiguous and determined on a project-by-project basis. The terms of reference usually decided upon under traditional plan reviews and development agreements. Generally only applied to a large urban or special projects like Halifax Gardens.

London	Wind	Discretionary Review Buildings above a specified threshold height are required to submit either wind tunnel test results or a recommendation by a wind engineering consultant.
Montreal	Sun-Wind	Discretionary Review Large developments which vary from the zoning bylaw are sometimes required to submit sun studies and wind tunnel test results depending on the planning and design issues identified.
Ottawa	Sunlight Access	Planning Policy Requirements Specific site studies of sun access are required, with emphasis placed on future development on south side of streets for buildings adjacent to pedestrian areas. Focus on sunlight conditions conditions in "shoulder" seasons.
	Wind-Shelter	Council approved Planning Policies Official Plan Amendment Modeling required to demonstrate compliance with criteria for wind in open pedestrian areas (malls, mini-parks, squares, etc.). Study includes buildings which are adjacent to open pedestrian areas; buildings located at corners of blocks; any mid-blocks in which the average height is more than 2/3 the average height of surrounding buildings, and any buildings directly across an abutting street. The policy has an option to allow wind modeling on the city model developed by the National Research, and 11 out of 22 new buildings have had wind model testing required based on the Official Plan policy.

Winnipeg	Wind	Design Approval Bylaw Developers are required to submit statements by wind engineers disclosing potential wind impacts and proposed mitigating measures as part of development review. Should the Design Board (a political body) feel the wind issues warrant further investigation, it can require scale-model tests. No performance standards are set; standards are based on recommendations by wind engineers.

United States Cities

City	**Environmental Quality**	**Type of Regulation**
New York	Daylight Access	*Two Options for Evaluating Compliance:* Height Limit i. Sky exposure curve. Curve starts at a height of 1.5 times the width of the street or avenue. The curve projects upwards from the property line. Performance Standard: ii. Daylight evaluation chart. Developments must average 75 percent exposure to pass. Squares in the graph are scored. Below 70 degrees the score is equal to 0.3 credit; above 70 degrees the score is equal to one full credit for each square of sky blocked. The method is computerized. Reflectivity rating can, for reflective surfaces, add to the score.
	Sunlight Access	Discretionary Review i. Conditional zoning approval requires shadow impact analysis (30 percent of Midtown projects).

		Performance Standards ii. Shadows on residential windows. Developments which exceed as of right heights (e.g. need conditional approval) require shadow analysis of windows adjacent or opposite the proposed development. The approval is discretionary. iii. Standards for sun access to parks are currently under development as a result of a study prepared for the New York Parks Council by the Environmental Simulation Laboratory at Berkeley.
	Wind Shelter	Performance Standard Sponsors of large development projects are required to conduct wind studies. The expected wind velocities in new or existing open spaces shall not exceed the mean gust reading measured in existing comparable open spaces. The wind studies are done as part of the Environmental Impact Study (EIS) process.
Boston	Daylight Access	Sunlight Blockage Limit A given project shall not exceed the blockage of the minimum zoning envelope. No citywide standard, but measured through environmental review process, optional and becoming less common. The methodology for measuring daylight access is similar to New York's Midtown daylight chart.
	Sunlight / Shadows	Height Zoning and Performance Standard i. Zoning ordinance has designated impact areas, "Boston Commons" and "Downtown Crossing." No net increase in shadow is permitted between 8 a.m. and 2:30 p.m. Specific developments are exempt from this ordinance.

		ii. Midtown Cultural District. No net increase in shadows is permitted between 8 a.m. and 2:30 p.m. iii. State legislation being considered prohibiting shadows on major open spaces one hour after sunrise to one hour before sunset.
	Wind	Performance Standard Preliminary designs and final designs are analyzed through wind tunnel testing. The final design analysis is quantitative. The mean wind speed shall not exceed 22 mph.
Chicago	Sunlight access	Discretionary Review Sponsors of major developments can be required to submit shadow analysis.
	Wind	Discretionary Review Sponsors of major development proposal can be required to submit wind studies.
Philadelphia	Sunlight access	Height Limits i. Building heights south of Chestnut and Walnut Streets are limited to prevent sunlight blockage.
		Discretionary Review Building applicants seeking variance or conditional use permits can be required to demonstrate shadow impacts.
Pittsburgh	Sunlight Access	Discretionary Review Sponsors of major developments are required to submit shadow analysis.

	Wind	Discretionary Review Sponsors of major developments are required to perform wind tunnel tests for preliminary designs and final design. Mitigation measure might be required during design review prior to zoning approval.
Charlotte, N.C.	Sunlight Access	Performance Standard In the Central Area, no development shall cast a shadow in excess of 20 feet onto residentially zoned property on September 21 (equinox) between the hours of 9 a.m. and 3 p.m., except for residential properties across the street.
San Francisco	Sunlight Access	Height Limits In inner city neighborhoods, the building height limits are set to protect sunlight to public open spaces and streets.
		Performance Standards Sun access standard for streets in the retail district and Market Street are set to protect sunlight access to sidewalks during intensive use periods.
		Sunlight Ordinance (Prop. K): Parks owned and operated by the Recreation Department, including parks, squares, and playgrounds, are protected by a 1984 city-wide standard (approximately 70 public open spaces) from one hour after sunrise to one hour before sunset. Two downtown open spaces, the Civic Center Plaza and Union Square, have a specific standard. The Planning Commission and Park Recreation Commission permitted an additional one percent shadow for both spaces.

Discretionary Review

Privately owned open spaces and open spaces owned by other city agencies are protected by a requirement to minimize shadow impacts on such spaces.

Wind

Performance Standard

A building form should not be used "which causes wind speeds to exceed eleven miles" per hour in areas where people walk and seven miles per hour in areas where people sit.

Other cities contacted:

Seattle, Washington
Minneapolis, Minnesota
St. Louis, Missouri
Portland, Oregon
Baltimore, Maryland